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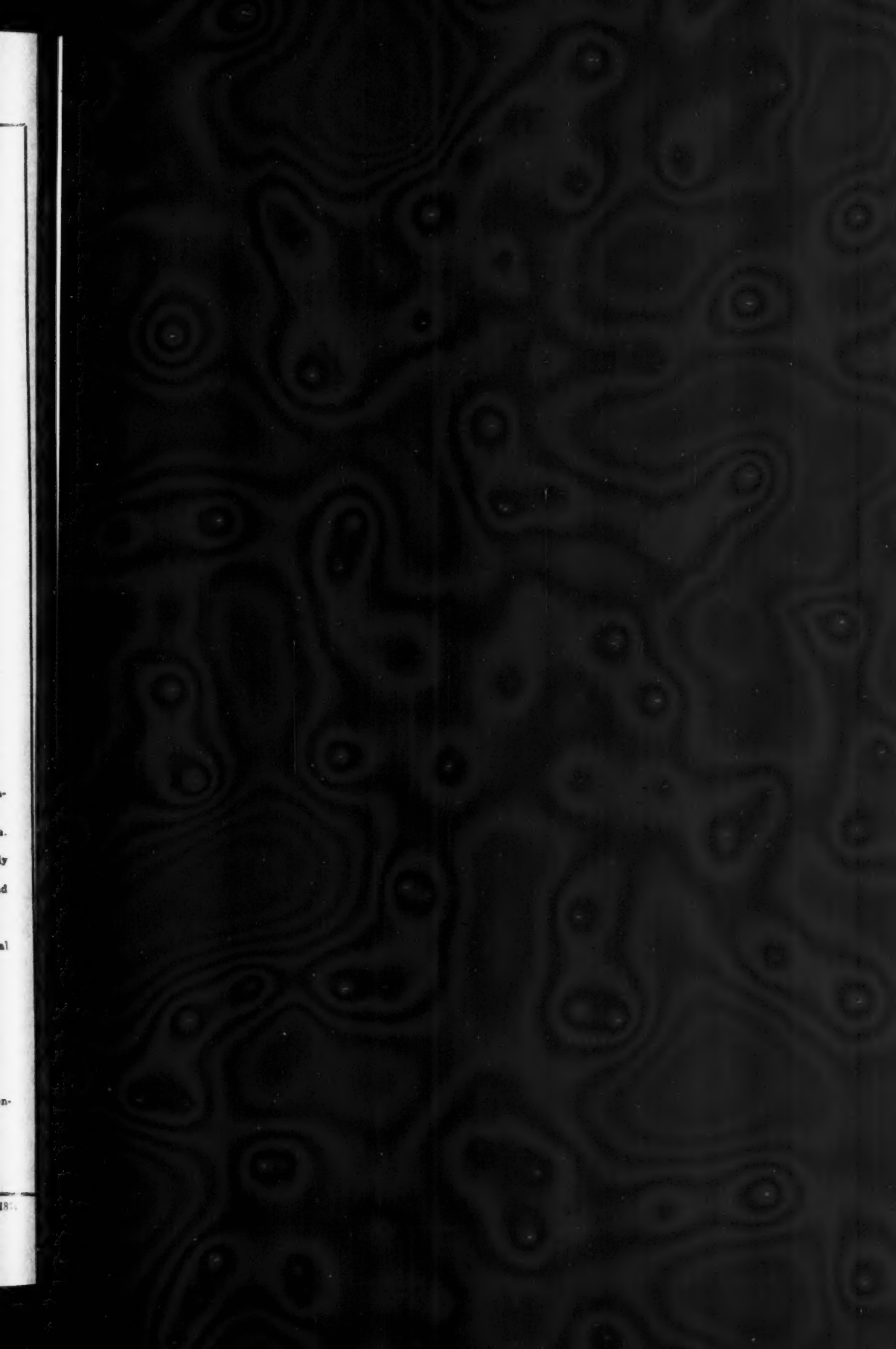

THE INFLUENCE OF MANGANIFEROUS SOILS ON THE ACCURACY OF THE QUINHYDRONE ELECTRODE

W. T. McGEORGE

Hawaiian Sugar Planters' Association Experiment Station

Received for publication August 20, 1928

The increasingly important position of soil reaction in soil fertility studies has stimulated much development in accurate methods of estimating slight variations in hydrogen- and hydroxyl-ion concentration in soils. The investigations of Sharp and Hoagland (7) on the application of the hydrogen electrode stand out prominently in this field of endeavor. But, as usually follows the extensive application of new analytical methods, limitations are often met in practice. In measuring the pH of neutral or slightly alkaline soils, the CO_2 equilibrium enters into the reaction and the observed voltages are often misleading. In some cases, hydrogen must be passed through the soil for long periods which too, is an objection. Also the electrode may show error in the presence of certain unsaturated substances or small amounts of active oxidizing agents, such as nitrate ions. Some have registered objection to the platinum black coating on the electrodes which is rapidly poisoned by certain materials.

In 1920, Billman showed that it was possible to form, by means of the organic compound quinhydrone, an electrode which could be used for making hydrogen-ion determinations and with which very constant voltages could be maintained. Out of this, the so-called quinhydrone electrode method for determining soil reaction has grown. The method was shown to have several advantages over the hydrogen electrode, notable among which were its simplicity, rapidity with which determinations could be made, and the fact that clean platinum electrodes were used. It is now being extensively applied in determining the reaction of soils.

The theory of the quinhydrone electrode has been ably stated and reviewed in a number of recent articles so will not be repeated here (1, 2, 3, 4). Suffice it to say, that the validity of the method is based largely upon the dissociation products of quinhydrone in aqueous solutions; namely, quinone, $C_6H_4O_2$, and hydroquinone, $C_6H_4O_2H_2$. The equilibrium of these products of dissociation is an essential feature in the accuracy of the method. It is the purpose of this article to present what appears to be a limitation in the application of the quinhydrone electrode in determining the reaction of soils.

EXPERIMENTAL

The quinhydrone electrode was prepared as described by Billman (2, 3). The special KCl–HCl half cell (0.01 *N* HCl : 0.09*N* KCl) was used. This was

connected by capillarity with a saturated KCl solution and this in turn by a KCl-agar bridge to the soil-water suspension to which a given weight of quinhydrone was added. Clean platinum foil was used for the electrodes. The difference in potential was measured with an L. N. students' type potentiometer and a sensitive galvanometer. Correction was made for temperature as in the following equation:

$$\text{pH} = \text{pH of KCl} - \text{HCl half cell} + \frac{\text{E.M.F.}}{0.000198\ T}$$

The same potentiometer and galvanometer were used in the comparative determinations with the hydrogen electrode.

The soils selected represented a wide variation in Hawaiian soil types and a reaction range of pH 4.6 to 8.0. A brief description of the soils follows:

1. A reddish yellow clay loam, acid soil, low fertility.
2. A black silty clay loam.
3. A yellowish brown silty clay loam.
4. A yellow silty clay loam.
5. A brown silty clay loam.
6. A chocolate brown silt loam, highly manganiferous type.
7. A heavy black clay, high magnesium soil, adobe type.
8. A black silt loam, highly organic.
9. A yellow silty clay loam.
10. A brown silty clay loam.
11. A yellow silty clay loam.
12. A red silty clay loam.
13. A silt loam, highly organic.
14. A reddish brown silty clay loam.
15. A red clay loam.
16. A brown silty clay loam.
17. A yellowish brown silty clay loam
18. A highly saline clay soil.
19. A red clay loam.
20. A red clay loam.
21. A red clay loam.
22. A red clay loam.

For the pH determinations, all soils were air-dry. Only boiled distilled water was used for the soil-water suspensions. The ratios of soil to water were 1:1, 1:2, and 1:5. On account of the high water-absorbing power of many Hawaiian soils, it is difficult to get a reading with the hydrogen electrode on a 1:1 ratio. Even where the mixture is of sufficient fluidity, the potential is very slow in reaching equilibrium, which may account for some of the discrepancies in this column of the table.

For the determinations with the hydrogen electrode the soil-water suspension was prepared one hour before the pH readings were taken. The soil-water suspensions for the quinhydrone electrode were also prepared one hour in advance, but the reagent was added immediately before the reading was taken.

During some preliminary tests, it was found that in most cases, 0.025 gm. quinhydrone was sufficient to give a constant reading whereas in others, larger amounts were required and there was a notable "drift." The procedure employed was to add 0.025 gm. of quinhydrone and take the reading at once. Another 0.025 gm. was then added and a second reading taken. This was continued until there was no further drift in the potential. The data are given in table 1 and shown graphically in figure 1.

TABLE 1

The pH of soils by hydrogen and quinhydrone electrodes at 1:1, 1:3, and 1:5 soil-water ratios compared with percentages of manganese in soils

SOIL NUMBER	HYDROGEN ELECTRODE			QUINHYDRONE ELECTRODE			PER CENT Mn_3O_4
	1:1	1:3	1:5	1:1	1:3	1:5	
1	4.63	4.65	4.75	4.38	4.81	4.86	0.05
2	4.83	4.76	4.95	4.73	5.05	5.03	0.02
3	4.88	4.92	5.14	4.80	5.15	5.24	0.04
4	4.93	5.14	5.22	4.73	5.22	5.37	0.07
5	5.19	5.48	5.61	5.41	5.54	5.58	0.04
6	5.61	5.82	6.05	7.28	7.46	7.72	4.53
7	4.97	5.76	6.23	6.10	6.26	6.71	0.06
8	5.31	5.78	5.68	5.66	5.87	5.83	0.09
9	5.42	5.76	5.91	5.68	5.79	5.83	0.07
10	5.47	5.76	5.98	5.75	5.92	5.92	0.13
11	5.81	6.19	6.37	6.08	6.26	6.30	0.13
12	6.12	6.39	6.44	7.20	7.63	7.70	0.34
13	6.32	6.25	6.74	6.60	6.66	6.68	0.03
14	6.66	6.79	6.88	6.72	6.85	6.88	0.07
15	6.66	6.86	7.15	7.88	8.14	8.06	0.20
16	6.96	6.90	7.05	7.16	7.31	7.38	0.08
17	6.57	6.88	7.10	6.76	6.96	6.97	0.13
18	7.50	7.71	8.01	7.79	8.00	8.14	0.03
19	7.81	7.50	7.67	8.02	8.27	8.36	0.13
20	7.38	7.42	7.50	8.36	8.48	8.54	0.33
21	7.34	7.52	7.45	8.11	8.44	8.36	0.16
22	7.25	7.34	7.08	8.11	8.31	8.36	....

The data in table 1 and in figure 1 show several soils in which there is a decided lack of agreement and among these is the highly manganiferous type. Manganese was then determined in all the soils by extraction with HCl, sp. gr. 1.115, and these data have been added to the table. By reference to the description of the soils, it will also be noted that in all cases where lack of agreement was found, the soil was a red clay type. Such types we consider to have been formed in a more arid environment, as distinguished from the humid, and therefore contain iron and manganese as the higher oxides. Manganese is present in such types in the form of small pellets of MnO_2 or as a coating of MnO_2 upon the surface of the soil particles. The evidence is therefore quite convincing

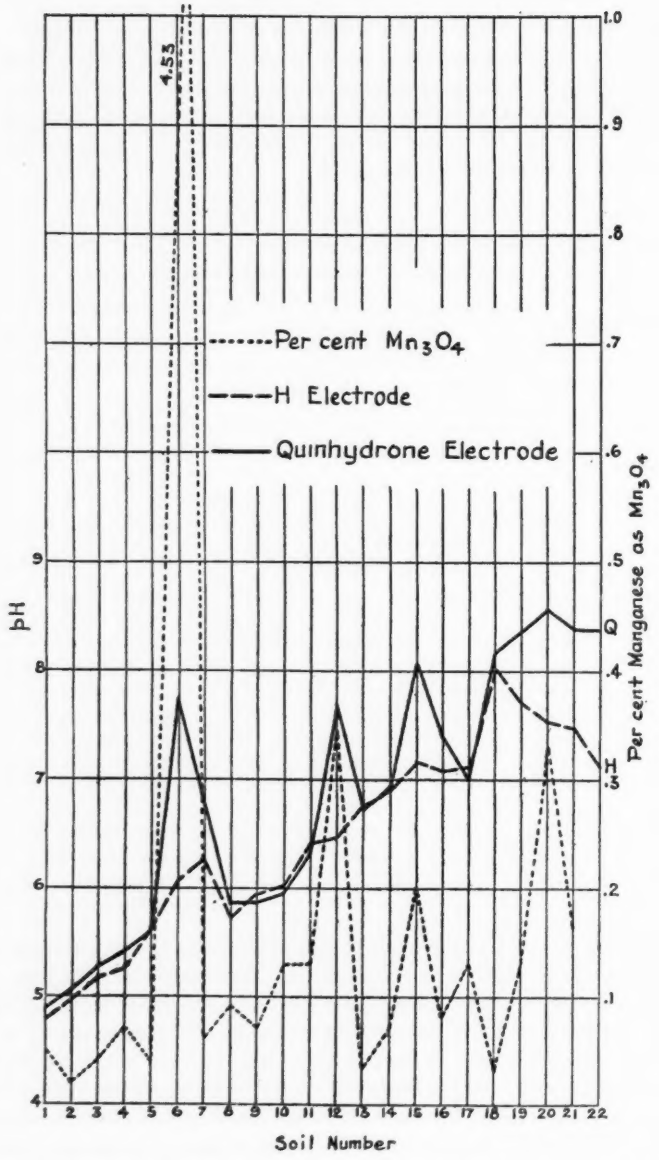
4.53
Per cent Mn_3O_4
H Electrode
Quinhydrone Electrode
pH
Per cent Manganese as Mn_3O_4
Q
H
Soil Number
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22
4 5 6 7 8 9
.1 .2 .3 .4 .5 .6 .7 .8 .9 1.0

FIG. 1. RELATION OF MANGANESE CONTENT OF SOIL TO pH AS DETERMINED BY QUINHYDRONE AND HYDROGEN ELECTRODES

that MnO_2 materially disturbs the equilibrium of the dissociation products of quinhydrone.

In view of this soil-water suspensions were prepared to which were added manganese dioxide, ferric oxide, and ferric hydroxide. The two latter had no effect upon the potentiometer reading. On the other hand, manganese dioxide produced a "drift" similar to that shown by the "truant" soils. These data are given in table 2.

The conclusion appears inevitable that the quinhydrone electrode is in error as applied to soils containing even small amounts of manganese dioxide. As a further check upon this, the two electrometric methods were compared with the colorimetric method. Of the 22 soils given in table 1, only 5 settled sufficiently to give a supernatant water extract which could be used for a colorimetric comparison. These soils were numbered 6, 8, 12, 16, and 18. In all five soils, the colorimetric and hydrogen electrode methods checked closely,

TABLE 2

Potentiometer readings in E.M.F.

MnO_2 ADDED	0.025 GM. QUINHYDRONE	0.050 GM. QUINHYDRONE	0.075 GM. QUINHYDRONE	
gm.				
None	0.130	0.130	0.130	Soil I
0.2	0.180	0.290	0.295	
0.5	0.230	0.295	0.300	
None	0.245	0.245	0.245	Soil II
0.2	0.295	0.345	0.345	
0.5	0.320	0.360	0.355	

whereas the quinhydrone electrode gave results much higher in 6 and 12, the manganiferous soils.

DISCUSSION

In the original work by Billman, 75 soils were used and comparisons between the hydrogen and quinhydrone electrodes made. In all except 7, close agreement was found, and in these 7 soils the disagreement was later found to be due to analytical errors. No mention is made as to any other factor arising in these discrepancies. Baver (1) has obtained satisfactory results, as has also Clark and Collins (4), with the quinhydrone electrode.

La Mer and Parsons (5), and La Mer and Rideal (6), have made rather intensive studies of the factors affecting the accuracy of the quinhydrone electrode which are of interest in connection with the above property of manganiferous soils. They found that the addition of an alkali to a solution of quinhydrone causes the latter to act as an auto-oxidizable substance according to the following equation:

$$C_6H_4(OH)_2 + O_2 \rightarrow C_6H_4O_2 + H_2O_2$$

In other words, that hydroquinone has the property of absorbing oxygen in alkaline solution. But, when the solution is acid, molecular oxygen is unable to effect any detectable oxidizing action upon hydroquinone although the latter is rapidly oxidized by certain *inorganic agents* possessing less powerful oxidizing potentials than oxygen, such as ferric ions. As previously stated, the validity of the quinhydrone method depends primarily upon the ratio of quinone to hydroquinone equal to unity. La Mer and Parsons name three factors which may cause this equilibrium to be disturbed.

1. The ionization of hydroquinone as a weak acid . . . .
2. Through hydroquinone or quinone being converted into the other by the action of some other active oxidizing or reducing component present in the system or by their unequal conversion into other bodies. The presence of such rapid oxidizing agents as ferric, permanganate, and dichromate ions or such rapid reducing agents as iodide, titanous, and chromous ions, to mention only a few, will obviously interfere with the use of the quinhydrone electrode, as all these substances react so rapidly with hydroquinone or quinone that they may be used to determine them in volumetric analysis.
3. Changes due to the presence of other electrolytes . . . .

CONCLUSIONS

The accuracy of the quinhydrone for the determination of soil reaction is greatly affected by the presence of small amounts of manganese dioxide.

It is not the purpose of this article to condemn the use of the quinhydrone electrode for soil analyses. The drift shown by the potentiometer with manganiferous soils is sufficiently rapid and characteristic as to warn the analyst against reporting erroneous results on such types.

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MINIMUM POTASSIUM LEVEL REQUIRED BY TOMATO PLANTS GROWN IN WATER CULTURES

EARL S. JOHNSTON AND D. R. HOAGLAND

University of Maryland and University of California[1]

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Concentration and volume are two distinct characteristics of a solution that should receive equal consideration in studies on plant nutrition. Too frequently the concentration of a solution is discussed without proper consideration of the volume involved. These two factors are in part analogous to the "intensity" and "capacity" factors of energy. The energy of a falling stream of water depends on the height of fall, the *intensity* factor, and on the quantity of water falling, the *capacity* factor. In a nutrient solution the initial concentration may be considered the intensity factor and the volume or total available supply, the capacity factor. Each is fundamental and should be considered in interpreting the results of plant nutritional experiments. In the soil these two characteristics are likewise important. The intensity factor may be regarded as the concentration of the soil solution at any given time, whereas the capacity factor is determined by the nature of the solid phases and by the volume of soil physiologically available for root dispersion.

An important question to be answered regarding the mineral nutrient requirements of plants and one which is not only scientifically interesting but also directly related to practical agriculture is, "What is the optimum concentration of a given element in a nutrient solution when the volume or total supply is not a limiting factor?" The term "optimum solution" here used is defined (4) as the "least concentration giving a yield equal to any higher concentration," that is, a minimum concentration giving a maximum yield. It is of course understood that such a question must be answered first for a particular plant grown under a given set of conditions, and later for other plants grown under other conditions.

Analyses of published data on the effect of concentration on plant growth frequently show a volume relationship. The total salt supply often becomes the limiting factor. Before it is possible to determine accurately the effect of concentration it seems necessary to eliminate or to minimize the factor of volume or total supply from the problem. The use of large volumes of solution as well as frequent changes is a move in the right direction. Parker and Pierre (12) conducted an experiment to determine the minimum concentration

[1] Acknowledgment is made of a grant from the American Potash and Chemical Company in partial support of this investigation.

of potassium necessary for maximum growth of corn and soybeans. One corn plant was grown in 7500 cc. of nutrient solution which was changed twice a day during the later part of the growing period when absorption was rapid. Under these conditions the average rate of change was approximately 10 cc. per minute per plant.

A few experiments have been reported in which solutions were continuously changed, but in these experiments the rates of flow per plant were too low to to make an accurate study of the minimum concentration. Trelease and Livingston (17) report a rate of 400 cc. per day per plant, which is approximately 0.3 cc. per minute. Shive and Stahl (14) have described and used a much simplified apparatus for the continuous renewal of solutions in a series of cultures. The delivery tubes of their apparatus were calibrated to supply each culture with 1 liter of new solution every 24 hours. If each culture contained a single plant the rate of flow would be approximately 0.7 cc. per minute. This apparatus has the advantage of simple construction and of being well adapted to the simultaneous study of a large number of solutions. Its capacity as described is not great enough for studies of minimum salt requirement, but it could doubtless be employed for such studies by using larger reservoir bottles and delivery tubes of greater bore.

EXPERIMENTATION

The experiments reported in this paper were designed to approximate the minimum potassium concentration required by the tomato plant. The work was carried out in the division of plant nutrition at the University of California with the Santa Clara Canner variety. Seeds were germinated between layers of moist filter paper and when the roots were 2 to 10 mm. long the young plants were transferred to a germination net similar to that previously described (8). After the seedlings had developed good roots and grown to approximately 2 to 3 cm. in length they were transferred to the culture solutions.

A special flowing solution apparatus, already described (9), was devised for these experiments. The plant containers were 5-gallon glazed earthenware jars. A special cover of heavy sheet copper was made to fit each of the 24 jars used in these experiments. Five holes were cut in each cover and then a heavy coating of tin was applied as a precaution against copper poisoning. These holes were large enough to receive the flat cork stoppers commonly used to support plants in ordinary fruit jars. The rate of flow of solution from the plant container was controlled by raising or lowering a siphon outlet which was fitted to each culture jar. The appearance of the apparatus at the beginning of one of the experiments is shown in plate 1, figure 1.

The general culture solutions used in the flowing solution experiments were made up from the following salts: calcium nitrate, magnesium sulfate, magnesium phosphate (secondary), manganese sulfate, and ferric tartrate. Since boron was found by Johnston and Dore (10, 11) to be absolutely necessary for the growth of the tomato plant, it was added as boric acid. To the general

culture solutions potassium was supplied as potassium sulfate. In the first experiment the approximate calculated concentrations of these nutrient ions were:

	SOLUTION A		SOLUTION B	
	p.p.m.	*milliequivalent**	*p.p.m.*	*milliequivalent**
Ca	200	10.0	200	10.0
Mg	67	5.5	67	5.5
K	*3.9*	0.1	*39.1*	1.0
NO_3	620	10.0	620	10.0
SO_4	199	6.3	242	7.8
PO_4	15	0.5	15	0.5
B	0.55	0.15	0.55	0.15
Mn	1	0.0364	1	0.0364
Fe	(Enough to keep plants green)			

*Values based on a liter of solution.

Actual analyses, however, showed these general culture solutions to contain less potassium than that calculated. The initial potassium concentration of the solutions used in the five experiments here reported are expressed as average values of several analyses. The solutions used in the other experiments were like these with the exception of the amounts of potassium sulfate.

The particular potassium concentrations employed were not chosen entirely arbitrarily, but the values were suggested by the magnitude of potassium concentrations found in the displaced solutions of certain soils which were being investigated with reference to the adequacy or inadequacy of their potassium-supplying power. It was essential to limit the experiments to one general type of culture solution, and therefore we are not now considering the possible physiological effects of different concentrations of other ions in solutions containing very low potassium concentrations. It need only be remarked that the solution used was in a general way very similar to many displaced solutions obtained from California soils.

Growth data

In the first of the five experiments with the flowing solution apparatus the 24 culture jars each containing four plants were divided into four groups. In order to study the possible relations between light conditions and potassium concentrations the plants in two groups were grown under a single thickness of cheesecloth within the greenhouse, the others were grown under ordinary greenhouse conditions. One group of plants in the cheesecloth shelter and one group of unshaded plants were supplied with the low potassium solutions (3.7 p.p.m.) whereas the other two groups received the high potassium solution (35.1 p.p.m.). For brevity these four culture groups are designated as *OH*, *OL*, *SH*, and *SL* where *O* represents open or unshaded conditions in the greenhouse; *S*, shaded conditions; *H*, high potassium; and *L*, low potassium. Thus

SH represents the group of plants grown in high potassium solution within the cheesecloth shelter in the greenhouse.

The seedlings of the first experiment were set out in their respective culture jars on August 17, 1926. The approximate rate of solution flow per plant per minute was 1.2 cc. By September 16, differences between plants of the high and low potassium groups were quite marked. Both the *OH* and *SH* plants were taller and had thicker stems. Flower buds were noted on the plants of the *OH* group on September 20 and on those of the *OL* group on September 25. On September 22 and October 2 samples of the solutions from the culture jars were taken for potassium analysis. These data are represented in table 1.

The solutions before they entered the culture jars had a pH value of 7.2 and the average values of the potassium analyses gave 35.1 p.p.m. and 3.7 p.p.m. for high and low cultures respectively. The figures given in table 1, when the growth of the plants is considered (see table 2), clearly indicate that the low potassium concentration used in this experiment with the given rate of flow (1.2 cc. per minute) was a limiting factor. The analyses of the residual

TABLE 1

Potassium analyses of flowing nutrient solutions in which tomato plants were growing

CULTURE	SEPTEMBER 22		OCTOBER 2	
	pH	*K(p.p.m.)*	*pH*	*K(p.p.m.)*
OH	7.2	13.2	7.4	8.5
OL	7.2	0.2	7.2	0.7
SH	7.4	10.7	7.4	11.6
SL	7.4	0.3	7.0	0.4

solutions on September 22 show that the plants removed enough potassium to reduce the concentration from 35.1 to 13.2 and 10.7 p.p.m. in case of the high potassium groups, *OH* and *SH*, and from 3.7 to 0.2 and 0.3 in the low potassium groups, *OL* and *SL*.

The plants were harvested on October 5 and 6; these data are given in table 2. The general appearance of the *OH* and *OL* groups prior to harvest can be seen in plate 1, figure 2. The *SH* and *SL* groups are within the cheese cloth shelter. The values for each group represent the average of 24 plants except in the case of the dry weight of tops, where 12 plants were used, the other 12 having been set aside for other purposes. Stem height was considered to be the distance from the upper surface of the cork stopper to the base of the terminal bud. At the time of harvest numerous flower buds were present on the plants of the *OH* group with full flowers appearing on about half the number. A few flower buds, none open, however, appeared on the plants of the *OL* group, but none was observed on any plants of the shaded groups.

Dry weight data (table 2) are perhaps the best criteria of growth. Objection may be raised to the small number of plants (twelve) used in each group.

For that reason the maximum and minimum dry weights as well as the average are recorded. When the data of the high and low potassium groups of each light condition are examined it will be noted that the minimum of the high group is greater than the maximum of the low potassium group in each of the two cases. There is no overlapping so that the differences in the averages are quite significant. Little doubt can exist that the amount of potassium is the limiting growth factor for plants of groups *OL* and *SL*.

Attention is called to the dry weight ratios of the two groups exposed to the two light conditions.

$$OL/OH = 5.2/13.6 = 0.38$$
$$SL/SH = 3.6/\ 9.2 = 0.39$$

Here it would appear that light intensity also limits growth, for the ratio of the low to high potassium cultures remains practically the same under two given light conditions. In other words, the low light intensity limits growth

TABLE 2

Average growth of tomato plants grown in solutions of high and low potassium content and under two different light conditions

GROUP	STEM HEIGHT			GREEN WEIGHT (TOPS)			DRY WEIGHT (TOPS)			DRY WEIGHT (ROOTS)
	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average
	cm.	*cm.*	*cm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
OH	98	118	70	165	220	104	13.6	17.8	10.4	5.6
OL	68	84	53	50	72	30	5.2	6.7	2.9	3.5
SH	117	127	93	130	230	72	9.2	16.3	5.3	3.0
SL	76	84	57	38	52	28	3.6	4.3	2.3	2.3

in the same proportion whether or not the potassium supply is a limiting factor. This is perhaps better seen when the fractions are rearranged thus:

$$SH/OH = 9.2/13.6 = 0.69$$
$$SL/OL = 3.6/\ 5.2 = 0.69$$

Apparently we have here an example of two limiting factors which are in effect operative at the same time. Considering the plants grown under shade and in a low potassium solution, evidently it was possible to increase their yield by either increasing the potassium concentration of the solution or by improving the condition of illumination, maximum yields being obtained, however, only when both factors were changed. None of the data now available make it possible to suggest an explanation of the mechanism involved in these relations. The actual percentages of potassium in the tissues of the shaded plants were higher than in the corresponding unshaded plants. Perhaps for the production of a given total quantity of dry matter a higher per-

centage of potassium is required with low light values than with high. In any case, experiments of this type have not only theoretical but also practical interest. For example, Russell (13) suggests that there may be a relation between sunshine and potassium fertilization with tomatoes and other plants. Incidentally, in making such comparisons, it is well to note that light values in a greenhouse are much lower than outside, and the quality of the light is also different. It remains to be determined how light values higher than those of the greenhouse, would be related to potassium concentrations in the culture solution.

This first experiment with the flowing solution apparatus clearly showed that a potassium concentration of 3.7 p.p.m. flowing at the rate of 1.2 cc. per minute per plant was below the minimum for the best growth of the tomato under the given conditions. The second experiment, therefore, was modified considerably. The cheesecloth shelter was removed and a single plant was grown

TABLE 3

Average weekly height of tomato plants in experiment 2, together with the maxima and minima of each group

WEEK ENDING	LOW POTASSIUM CONCENTRATION			HIGH POTASSIUM CONCENTRATION		
	Average	Maximum	Minimum	Average	Maximum	Minimum
	cm.	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*
November 4, 1926	2.5	3.1	2.0	2.5	3.0	2.2
November 11, 1926	6.1	7.1	5.4	6.2	6.6	5.5
November 18, 1926	12.5	14.0	11.2	13.0	14.1	11.7
November 25, 1926	27.0	29.4	24.5	27.8	31.2	25.1
December 2, 1926	39.5	44.0	34.5	43.5	52.0	39.2
December 9, 1926	59.1	64.0	54.3	62.7	71.5	57.5
December 16, 1926	84.9	92.6	77.8	91.7	101.8	82.5

in each 5-gallon culture jar. The initial potassium concentrations of the solutions were 3.7 and 35.1 p.p.m. for the *L* and *H* cultures respectively. Each of the two groups contained 12 plants while the rate of flow was 4.6 cc. per minute per plant. The experiment was started October 28 and ended December 16, 1926.

Little, if any, difference existed between the plants of the two groups until November 27, at which time the high potassium plants appeared to be somewhat better in general vigor and their stems slightly thicker. On December 2 measurable differences occurred in the average stem height data, as recorded in table 3.

At time of harvest, the stems of the plants in the high potassium groups were distinctly thicker than those in the low potassium group. Flower buds had developed to some extent in both groups, but none had opened. Slight tip burn appeared on some leaves in both groups while a few leaves on three

of the low potassium plants were somewhat spotted. This particular spotting is characteristic of potassium deficiency in the tomato and resemble that found in the potato under similar conditions. Incidentally it is interesting to note that similar leaf spotting was observed with tomato plants grown in a certain California soil, the displaced solution of which contained potassium in a concentration very similar to that of the low potassium solution used in the present experiments. Figure 1 of plate 2 illustrates this condition of the tomato leaf. The green and dry weights of the plants in the second experiment are given in table 4.

The plants of the two groups in experiment 2 were more nearly alike in size than those of the high and low potassium groups in experiment 1. However, the evidence presented in experiment 2 shows that under these conditions,

TABLE 4

Average green and dry weights of tomato plants in experiment 2, together with the maxima and minima of each group

	LOW POTASSIUM CONCENTRATION			HIGH POTASSIUM CONCENTRATION		
	Average	Maximum	Minimum	Average	Maximum	Minimum
	gm.	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
Green weight						
Tops	110	139	89	209	251	179
Roots	26	33	19	31	35	23
Total	136			240		
Dry weight						
Tops	7.2	9.2	5.7	10.8	13.0	8.5
Roots	1.1	1.4	0.9	1.0	1.2	0.8
Total	8.3			11.8		

3.7 p.p.m. of potassium in a solution flowing at the rate of 4.6 cc. per minute per plant was less efficient than 35.1 p.p.m. of the control solution in producing growth.

A third experiment was carried out similar to experiment 2 but differing only in the rate of flow. The low potassium solutions passed through the culture jars at the rate of 8 cc. per minute per plant. The rate of the high potassium solution was 4 cc. per minute per plant. This experiment was conducted from January 17 to February 21, but even under the increased rate of flow, growth of the tomato plants in the low potassium solution (3.7 p.p.m.) did not equal that of the control plants. Analyses of the residual solution on the last day of the experiment showed only a slight drop in the potassium concentration. The original concentration of potassium was more nearly maintained in this experiment than in any of the others.

Experiment 4 was quite similar to experiment 3 except for one important modification. The same rates of flow were maintained, but the concentration of potassium in the *L* group was increased from 3.7 to 4.9 p.p.m. The experimental period included the time from February 21, to April 7, 1927, and more nearly equalled the length of periods used in the first two experiments. Analyses of the residual solutions on the last day of the experiment showed that the potassium concentrations had been reduced to 2.0 and to 30.6 p.p.m. for the *L* and *H* cultures respectively. The similarity in growth of the plants in these two groups is shown in table 5.

TABLE 5

Average weekly height and average green and dry weights of tomato plants in experiment 4

WEEK ENDING	LOW POTASSIUM CONCENTRATION	HIGH POTASSIUM CONCENTRATION
	Average weekly height	
	cm.	*cm.*
February 28, 1927	1.9	1.8
March 7, 1927	4.2	4.3
March 14, 1927	8.6	8.5
March 21, 1927	20.0	18.9
March 28, 1927	33.9	31.4
April 4, 1927	46.7	43.5
April 7, 1927	54.8	50.9
	Green weight	
	gm.	*gm.*
Tops	13.3	12.9
Roots	3.0	2.8
Total	16.3	15.7
	Dry weight	
	gm.	*gm.*
Tops	8.8	8.3
Roots	1.4	1.3
Total	10.2	9.6

Under the conditions of these experiments it would appear that the tomato plants required a minimum of approximately 5 p.p.m. initial concentration of potassium when the rate of flow was 8 cc. per minute per plant. In order, however, to test out again the solution of slightly lower concentration flowing at the same rate, experiment 5 was carried out. This was a duplicate of experiment 3, but was conducted at a later date, April 11 to May 23, 1927. The results were similar to those of experiment 3 in that it seemed quite clear that the potassium concentration was below the minimum requirement of the tomato plant. The general appearance of the plants in both sets was very good, but the stems of the high potassium plants were definitely thicker and

the leaves longer than those of the low potassium group. The somewhat stockier appearance of the high potassium plants is indicated in plate 2, figure 2, where a representative plant of each group is shown.

The data from the five experiments on the relation of the minimum potassium level in flowing nutrient solution to the growth of tomato plants are summarized in table 6. With the exception of experiment 3 the durations were approximately equal. The initial potassium concentrations of the solutions are the average values obtained from analyses of the inflowing solutions. During the progress of each experiment, samples of solutions were collected from the plant containers for potassium analysis, but only the analyses of the final samples taken at dates of harvest are given in the table. When the

TABLE 6

Relation of potassium in flowing nutrient solutions to growth of the tomato plant

	EXPERIMENT 1		EXPERIMENT 2		EXPERIMENT 3		EXPERIMENT 4		EXPERIMENT 5	
Period:	*1926*		*1926*		*1927*		*1927*		*1927*	
Beginning	Aug 17		Oct. 28		Jan. 17		Feb. 21		Apr. 11	
Ending	Oct. 5		Dec. 16		Feb. 21		Apr. 7		May 23	
Duration (days)	49		49		35		45		42	
Group	*L*	*H*	*L*	H	*L*	*H*	*L*	*H*	*L*	*H*
Approximate rate of flow per minute per plant...*cc.*	1.2	1.2	4.6	4.6	8.0	4.0	8.0	4.0	8.0	4.0
K in solutions										
Initial...*p.p.m.*	3.7	35.1	3.7	35.1	3.7	35.1	4.9	35.1	3.7	35.1
Residual...*p.p.m.*	0.7	8.5	1.4	23.1	3.5	34.6	2.0	30.6	1.1	24.3
Average height...*cm.*	68.0	98.0	84.9	91.7	34.1	38.6	54.8	50.9	49.4	48.1
Dry weight										
Tops...*gm.*	5.2	13.6	7.2	10.8	1.8	2.8	8.8	8.3	12.3	19.8
Roots...*gm.*	3.5	5.6	1.1	1.0	0.2	0.3	1.4	1.3	1.8	1.9
Total...*gm.*	8.7	19.2	8.3	11.8	2.0	3.1	10.2	9.6	14.1	21.7

plants were younger the potassium concentrations were not reduced to the extent they were at time of harvest. The greatest amount of potassium reduction from a concentration of 3.7 p.p.m occurred in experiment 1. Here the rate of flow was lowest. An almost equal reduction occurred in experiment 5, but in this case the rate of flow was much higher. This greater rate of flow should tend to prevent much reduction in the residual solution. However, seasonal conditions were perhaps more conducive to vigorous growth in experiment 5 than in experiment 1 as is indicated by the dry weight data.

The least reduction of potassium from the original concentration of 3.7 p.p.m. occurred in experiment 3. This is not surprising, for the duration of this experiment was only 35 days and in addition the climatic conditions at that time of year were perhaps poorest for growth. These plants were un-

doubtedly less mature than those in the other experiments. This is clearly shown by the dry weights as well as the height measurements.

In experiment 4 the total dry weights of the low and high potassium groups were practically the same. It is therefore reasonable to conclude that a solution originally containing 4.9 p.p.m. potassium flowing at the rate of 8 cc. per minute per plant is as good for growing these tomato plants as is the control solution containing 35.1 p.p.m. potassium flowing at the rate of 4 cc. per minute per plant. The analyses of the final samples collected in this experiment indicate that plants in both the *L* and *H* groups were rapidly reducing the potassium concentrations of their respective solutions.

An interesting observation was made in connection with certain potassium analyses of the solutions collected in experiment 5. The outlet tubes from the culture jars were so arranged that composite samples of the residual solutions could be collected by merely placing empty vessels under the ends of the drain tubes. On May 15, samples were collected at 7.30 a. m. and 4.30 p.m. and on May 22, similar samples were obtained at 9 a. m. and 6.30 p. m. The following potassium concentrations, expressed as parts per million, were found:

	LOW POTASSIUM		HIGH POTASSIUM	
	a.m.	*p.m.*	*a.m.*	*p.m.*
May 15	2.24	1.60	28.38	23.88
May 22	1.32	0.80	24.40	24.16

In each case, samples collected in the early morning contained more potassium than samples collected in the late afternoon. This is taken to indicate a more rapid absorption of potassium by the plants in the afternoon than in early morning and is probably related to differences in light. Each sample was collected in a 2-quart fruit jar requiring from 30 to 60 minutes. This length of time together with the lag of solution movement in the 5-gallon culture jars would place the exposure periods of the plants well within periods of relatively weak and strong light. If this be true it is in agreement with the work reported by Hoagland and Davis (6) and by Hoagland, Hibbard, and Davis (7) on the absorption of ions as influenced by light.

Chemical data

Chemical analyses were made on the dried plant material from the five experiments. These data, expressed as percentages of water-free material, are presented in table 7. The actual amounts of the elements noted in the table may be determined by multiplying the percentages by the corresponding dry weights noted in table 6.

It will be seen that a very great difference exists between the tops of the plants of the two groups in experiment 1 with respect to the accumulation of certain elements. Accompanying the great depression in the percentage of

potassium found in the *L* group as compared to that in the *H* group of plants, there is an increase in the percentage of calcium, magnesium, and phosphate. It will be remembered (see table 6) that in the *L* cultures of experiment 1, the potassium concentration of the nutrient solution was 3.7 p.p.m. flowing at the rate of 1.2 cc. per minute per plant. In experiment 2 this rate was increased to 4.6 cc. per minute per plant. Here considerable increase in dry weight of the low potassium plants was noted. The percentage of potassium in the plants of the *L* group in experiment 2 was double that found in experiment 1. Although the percentage of potassium in the *H* group was also greater than in experiment 1, nevertheless the percentage increase was greater for the *L* group plants.

TABLE 7

Analyses of tomato plants grown in flowing solutions of low and high potassium concentrations, expressed as percentages of water-free material

	EXPERIMENT 1		EXPERIMENT 2		EXPERIMENT 3		EXPERIMENT 4		EXPERIMENT 5	
Portion of plant analyzed	Tops		Tops		Tops		Tops		Tops	
Group	*L*	*H*	*L*	*H*	*L*	*H*	*L*	*H*	*L*	*H*
K	1.94	5.75	3.99	9.08	7.40	9.02	3.68	3.77	3.71	5.90
Ca	3.26	2.25	4.15	3.46	3.77	3.27	3.77	3.50	3.46	2.82
Mg	0.72	0.44	0.95	0.68	0.98	0.84	0.92	0.83	0.80	0.56
N	3.94	3.85	3.98	4.72	6.18	6.33	5.23	5.17	4.41	4.26
PO_4	2.84	1.78	3.71	3.11	3.67	3.21	4.23	4.21	2.79	2.35
Portion of plant analyzed	Roots		Roots		Roots		Roots		Roots	
Group	*L*	*H*	*L*	*H*	*L*	*H*	*L*	*H*	*L*	*H*
K	1.12	3.47	1.31	3.05	3.24	6.17	3.57	6.66	1.45	3.47
Ca	1.66	1.88	1.31	1.39	1.44	1.47	1.70	1.45	1.27	1.31
Mg	1.58	0.93	1.62	0.54	1.50	0.60	1.39	1.12	1.72	1.05
N	4.80	5.23	4.89	4.61	5.08	4.79	4.24	4.62	4.95	4.91
PO_4	5.14	4.00	4.98	3.25	7.16	5.79	6.18	5.51	5.56	4.59

Less difference is noted between the percentages of calcium, magnesium, and phosphate of the two groups (*L* and *H*) in experiment 2 than in experiment 1. These differences progressively decrease in the order of the first four experiments. The percentages of elements found in the plants of the *L* and *H* groups in experiment 4 are more nearly alike than in any of the other experiments. In this experiment the solution rate of flow was 8 cc. per minute per plant and the potassium concentration 4.9 p.p.m. for the *L* group of plants. Because of the similarity in chemical composition as well as the similarity in general growth appearances of the plants in the *L* and *H* groups of experiment 4 it may be concluded that optimum growth can be obtained at a minimum potassium concentration of 4.9 p.p.m. under the conditions of this experi-

ment. It is, of course, realized that there may be other measurements and analyses, which, had they been made, would show the two groups to be quite dissimilar, but with the criteria here used these groups appear identical within the limits of variability and experimental error.

Root data similar to those for the tops of the plants are also given in table 7. In each of the five experiments the percentage of magnesium is higher in the *L* group of plants. Phosphate is also higher in the roots of these plants. Not much difference in the percentage of nitrogen is apparent in the two groups. In this respect there is a similarity between the roots and tops. The roots, however, differ from the tops with respect to their calcium relations since in

TABLE 8

Analyses of tomato plants grown in flowing solutions of low and high potassium concentrations, expressed as milli-equivalents per gram of plant

	EXPERIMENT 1		EXPERIMENT 2		EXPERIMENT 3		EXPERIMENT 4		EXPERIMENT 5	
Portion of plant analyzed	Tops		Tops		Tops		Tops		Tops	
Group	*L*	*H*	*L*	*H*	*L*	*H*	*L*	*H*	*L*	*H*
K	0.50	1.47	1.02	2.32	1.89	2.31	0.94	0.96	0.95	1.51
Ca	1.63	1.12	2.07	1.73	1.88	1.63	1.88	1.75	1.73	1.41
Mg	0.59	0.36	0.78	0.56	0.81	0.69	0.76	0.68	0.66	0.46
NO_3	2.81	2.75	2.84	3.37	4.41	4.52	3.73	3.69	3.15	3.04
H_2PO_4	0.30	0.19	0.39	0.33	0.39	0.34	0.45	0.44	0.29	0.25
Sum of bases K, Ca, Mg	2.72	2.95	3.87	4.61	4.58	4.63	3.58	3.39	3.34	3.38
Portion of plant analyzed	Roots		Roots		Roots		Roots		Roots	
Group	*L*	*H*	*L*	*H*	*L*	*H*	*L*	*H*	*L*	*H*
K	0.29	0.89	0.34	0.78	0.83	1.58	0.91	1.70	0.37	0.89
Ca	0.83	0.94	0.65	0.69	0.72	0.73	0.85	0.72	0.63	0.65
Mg	1.30	0.76	1.33	0.44	1.23	0.49	1.14	0.92	1.41	0.86
NO_3	3.43	3.73	3.49	3.29	3.63	3.42	3.03	3.30	3.53	3.50
H_2PO_4	0.54	0.42	0.52	0.34	0.75	0.61	0.65	0.58	0.59	0.48
Sum of bases K, Ca, Mg	2.42	2.59	2.32	1.91	2.78	2.80	2.90	3.34	2.41	2.40

both the *L* and *H* groups the percentages of calcium contained in the roots are very similar, but this is not true of the tops.

In order to show to what extent the actual chemical units replace each other, the data given in table 7 have been calculated to milliequivalents per gram of dry plant material. These values are set forth in table 8.

The milliequivalents of potassium in the plant tops of the *L* groups of experiments 1, 2, 3 and 5, are appreciably less than those of the corresponding *H* groups. On the other hand the milliequivalents of calcium and magnesium are higher in the *L* groups. The sums of the milliequivalents of potassium, calcium, and magnesium were determined for each group and the percentages of potassium based on these sums are as follows:

	EXPERIMENT 1		EXPERIMENT 2		EXPERIMENT 3		EXPERIMENT 4		EXPERIMENT 5	
	L	*H*	*L*	*H*	*L*	*H*	*L*	*H*	*L*	*H*
Sum	2.72	2.95	3.87	4.61	4.58	4.63	3.58	3.39	3.34	3.38
Per cent	18	50	26	50	41	50	26	28	28	45

It is rather remarkable that such a constant relationship (approximate value of 50 per cent) exists between potassium and the other two elements in all of the *H* groups, except that of experiment 4. This relationship is especially interesting since the plants had been grown at different times of the year. Just why the plants in experiment 4 were an exception is not known. Both groups in this experiment had practically the same value. From these data it appears that the plants grown in potassium-deficient solutions tend to accumulate a greater amount of calcium and magnesium than when they are fully supplied with potassium. The replacement of calcium and magnesium in the plant tops by potassium is perhaps better seen when the *increase* of calcium and magnesium in the *L* groups over that found in the *H* groups is compared with the *decrease* of potassium in the *L* groups below that in the *H* groups.

	EXPERIMENT 1	EXPERIMENT 2	EXPERIMENT 3	EXPERIMENT 4	EXPERIMENT 5
Ca and Mg increase	74	56	37	21	52
K decrease	97	130	42	2	56

It is also desirable to consider the data from the point of view of the total number of milliequivalents of bases (K, Ca, Mg) contained in the plants of the *H* and *L* groups (table 8). In both the roots and tops there is evident a marked tendency for a decrease in potassium to be compensated by a chemically equivalent amount of calcium and magnesium. Thus the relative proportions of the different bases are subject to more radical alteration than is the total base content of the plant. This may be important as bearing on the internal equilibrium between mono- and divalent cations.

The total number of grams of potassium per plant (expressed separately for tops, roots, and total) is presented in table 9. These data are compared with the potassium concentrations of the solutions surrounding the plant roots. The volume of the plant containers was approximately 5 gallons each. The total maximum number of grams of potassium to which the roots were exposed at any one moment is given in the last line of the table. In reality the actual values were perhaps below these figures, especially when the plants were well grown.

It will be noted that the number of grams of potassium found in the roots was never greater than that in the total volume of solution surrounding them. On the other hand the number of grams found in the tops was always greater

than that found in the nutrient solutions, with two exceptions, the *H* groups in experiments 3 and 4. It is especially interesting to note there was more potassium in the tops of all the *L* groups than in the solutions surrounding their roots. While more total potassium was taken up by the *H* group plants than by the *L* group plants, the ratio of the amounts absorbed by the *L* groups to the concentration of their nutrient solutions was far greater than in the case of the *H* group plants.

If it be assumed that nearly all of the potassium found in the roots and tops was present in the cell sap in dissolved state, then the concentration of potassium in the sap must have been from a hundred to a thousand times greater than in the culture solution which bathed the root system. The factor of concentration (concentration in sap divided by concentration in solution) would be far higher for the solution of low concentration than for the one of high concentration. The relations are consistent with experiments on other types of agricultural plants and on certain aquatic plants, such as Nitella.

TABLE 9

Total grams of potassium per plant compared with the possible maximum potassium concentration of the nutrient solutions surrounding the plant roots at any given time

	EXPERIMENT 1		EXPERIMENT 2		EXPERIMENT 3		EXPERIMENT 4		EXPERIMENT 5	
Group	*L*	*H*	*L*	*H*	*L*	*H*	*L*	*H*	*L*	*H*
Tops	0.101	0.782	0.287	0.981	0.133	0.253	0.324	0.313	0.456	1.168
Roots	0.039	0.194	0.014	0.031	0.003	0.019	0.050	0.087	0.026	0.066
Total	0.140	0.976	0.301	1.012	0.136	0.272	0.374	0.400	0.482	1.234
Solution concentration p.p.m. K	3.7	35.1	3.7	35.1	3.7	35.1	4.9	35.1	3.7	35.1
Approximate gm. K in 5 gallons	0.070	0.664	0.070	0.664	0.070	0.664	0.093	0.664	0.070	0.664

The chemical data here presented indicate that a potassium concentration of approximately 5 p.p.m. in the nutrient solution flowing at the rate of 8 cc. per minute per plant was exactly at, or slightly below, the minimum required by the tomato plants in these experiments. A slightly greater concentration or a slightly greater rate of flow would, in all probability, merely result in a somewhat higher concentration of potassium in the root sap. So far as can be seen at present, such an increase would be of little or no benefit to the plants, at least for the stages of growth under observation.

DISCUSSION

The main purpose of the five experiments here reported was to approximate a minimum potassium concentration necessary for optimum growth of the tomato plant. The effect of volume or total supply of nutrients is a serious handicap in any study of this sort. Stiles (16) emphasizes this matter in his statement, "The extent to which concentration of the nutrient solution can

act as a limiting factor is difficult to examine, because from the moment the plant roots are put in the solution the concentration will be altering. It was in an attempt to minimize this difficulty that the writer changed the water culture solutions at frequent intervals. Even then the concentration of the nutrient solution will only remain very approximately constant when the rate of growth is slow." Hoagland (4) voices a similar criticism in his discussion of several salt nutrition studies in which sufficient distinction was not made between "supply of nutrients and concentration of nutrients." A number of investigators have made use of large volumes of solution while others have changed the plant nutrient solutions frequently in order to maintain a fairly constant concentration and to reduce reaction changes to a minimum. It is obvious, however, that the use of rapidly flowing solutions more nearly fulfills the requirements for studies of minimum salt level than any other method so far devised. In pointing out the importance of continuous renewal of nutrient solutions for plants, Trelease and Livingston (17) state, "If the rate is rapid enough, the discarded solution will not be significantly different from the inflow, and the roots may be said to have been in a known set of chemical surroundings throughout the culture period."

One further point should be mentioned in any critical review of experiments with flowing culture solutions. The determinations of concentration are made on samples representing the main body of the solution in which the root system is immersed. The concentration of any element in the films of solution surrounding the absorbing root membranes is unknown. The degree to which a given concentration is maintained in these films may depend in part on the thoroughness with which the solution is kept mixed mechanically, by rapid flow of solution or by some other form of stirring.

It is not necessary at this time to enter into a discussion of the interpretation of solution culture data in terms of soil problems, but it seems desirable to mention the point that it is possible that plants growing in soil or sand may develop a much greater total absorbing root surface than in a culture solution, thus providing to a greater or lesser extent a means of compensation for low soil solution concentrations. On the other hand, earlier comparisons of solution and sand cultures each involving the same total amounts of nutrient, showed that barley plants accumulated greater percentages and amounts of mineral elements from the solution condition, notwithstanding the greater root development occurring in the sand cultures. Presumably these effects were explained by the ease of diffusion (or mixing by convection currents) in the solution cultures. However, the comparison of sand and solution cultures is not the same as that of soil and solution cultures, since the soil has a "supplying" power of its own. We have then, entering into the equation, in addition to concentration effects, relative areas of absorbing root surfaces, rates of diffusion or of mixing in culture solutions, and rates of solution of solid components in the soil. Unfortunately we have no means of evaluating certain of these factors, and therefore we cannot make any accurate comparison between soil solutions and artificial culture solutions.

Both the growth data and the chemical analyses of the plants and solutions in the five experiments reported in this paper indicate the minimum low level of potassium concentration to be approximately 5 p.p.m. for the tomato plants grown under the climatic and other conditions of the experiments. This is in good agreement, as to general magnitude involved, with results reported by the Arkansas Experiment Station (1) in determining the minimum amount of potassium needed for plant growth. These results led to the conclusion that between 3 and 5 p.p.m. potassium seemed sufficient for best growth of the tomato. Parker and Pierre (12) in their work at Alabama with corn and soybeans varied the potassium concentrations of their nutrient solutions from 0.5 to 25 p.p.m. Although maximum growth of corn was obtained in the solution of 10 p.p.m. and that of soybean in the solution of 25 p.p.m., nevertheless the growth obtained in solutions of 2 p.p.m. potassium was practically as good. These authors believe that the results obtained show that both plants will make maximum growth at potassium concentrations of 2 p.p.m. or possibly less. In comparing results obtained by different investigators it is desirable to emphasize once more the necessity for keeping in mind climatic conditions, variety of plant, and significance of data on basis of plant variability. It is not to be expected that exact and fixed values will ever be established but only that a better understanding will be obtained of the magnitudes involved.

It is not the purpose of the present paper to outline the rôle of potassium in the physiology of the tomato plant, but the influence potassium plays in its effect on the absorption of other elements cannot be overlooked. It has been known that one ion frequently influences the absorption of other ions and that sodium may be substituted for potassium to a certain extent. Experiments with barley (5) at the California station, clearly suggest that sodium and potassium ions may exert a depressing effect on the absorption of calcium ions. The interrelations of potassium, calcium, and magnesium as indicated in these experiments are consistent with those found in experiments of various types made on different plants in California. These experiments include studies made on citrus and walnut seedlings by Haas and Reed (3). Ginsburg (2) working with soybean plants grown in culture solutions each lacking a definite element, found the average composition (expressed as percentage) of the plants deficient in potassium to be the following as compared with plants grown in a complete solution:

	ASH	Ca	Mg	N
Complete solution.....	13.31	1.34	1.10	3.22
Potassium-deficient solution.....	12.69	3.15	1.15	4.55

Here an increase of calcium is noted in the potassium-deficient cultures. These observations are in general agreement with the tomato experiments in that the amounts of calcium absorbed decreased as the amounts of potassium increased, but no agreement was found regarding the magnesium and

nitrogen relations. With the tomato, little if any relation was manifest between the potassium and nitrogen content of the plants, the percentage of nitrogen remaining quite constant in all five experiments. No direct comparison can be made, however, for in Ginsburg's experiments potassium was completely lacking, and, furthermore, soybean plants were used.

The spotting of tomato leaves was very characteristic of plants grown in potassium-deficient solutions. These spots were dark brown and appeared first in the older leaves. This condition occurred only where the potassium supply was extremely low. Similar symptoms of "potash hunger" have been observed in other plants such as the potato, cotton, buckwheat and bean. Regarding "potash hunger" symptoms, Sorauer (15) states, "At first near the leaf edges and then later scattered over the whole surface of the leaf, appear yellowish spots which rapidly turn brown or often change to white, while the petioles and veins together with the immediately adjacent tissues remain green. Finally the leaves dry up, beginning usually at the edges, with a dark brown color." This describes very well the conditions occurring in the tomato plant when the potassium supply becomes greatly depleted. These conditions were more frequently observed in cultures of other experiments where the solutions were not changed. However, in this series of experiments, where the potassium concentration was low, and the rate of flow slow, the spotting appeared. This peculiar leaf reaction gives promise of being a reliable index of potassium deficiency of tomato plants grown in nutrient media.

SUMMARY

Concentration and volume are two distinct characteristics of a plant nutrient solution. In order to determine the minimum concentration of a given element that will produce optimum growth, the volume of the solution or total supply should be sufficiently large that it will not become the limiting factor. With a newly devised flowing solution apparatus, experiments were undertaken to determine the minimum potassium level requirement of the tomato plant. Under the given experimental conditions, which were kept within a range for good growth, it was found that optimum growth was maintained at a potassium concentration of approximately 5 p.p.m. at the intake. The rate of flow for such a solution averaged 8 cc. per minute per plant. The plants were grown for a period of 45 days. In experiments where the initial potassium concentration of 3.7 p.p.m. was reduced to 0.7 p.p.m. or even to 1.4 p.p.m., actual analysis of the plants showed a marked decrease in potassium absorbed and a tendency toward increased calcium, magnesium, and phosphate absorption as compared with check plants. A characteristic spotting of leaves indicating "potash hunger" is very marked in tomato plants grown in solutions in which the potassium concentration is maintained below a certain level. Attention is called to certain interesting relations between potassium concentrations and light values, as suggested by one of the experiments.

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PLATE 1

FIG. 1. Apparatus for controlling the flow of nutrient solutions.

FIG. 2. Tomato plants of the unshaded high and low potassium groups of experiment 1, together with the cheese cloth shelter containing the shaded groups of plants.

FIG. 1

FIG. 2

PLATE 2

FIG. 1. Spotting of tomato leaf (left) resulting from potassium deficiency, compared with normal leaf (right).

FIG. 2. Representative plants of low (3.7 p.p.m.) and high (35.1 p.p.m.) potassium cultures of experiment 5.

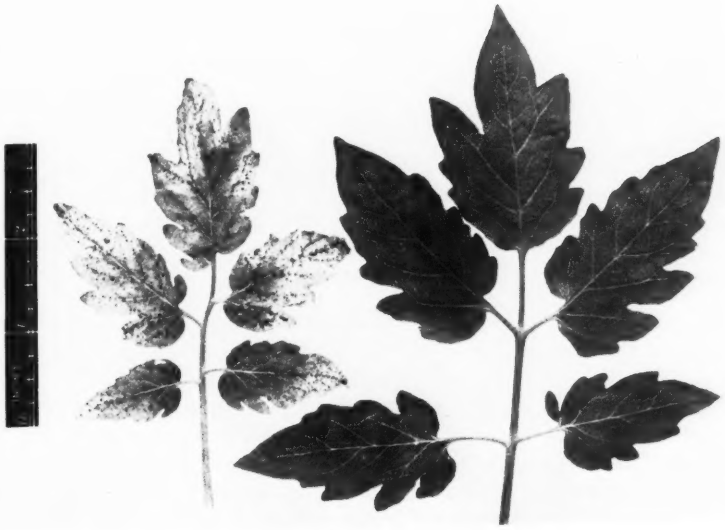

FIG. 1

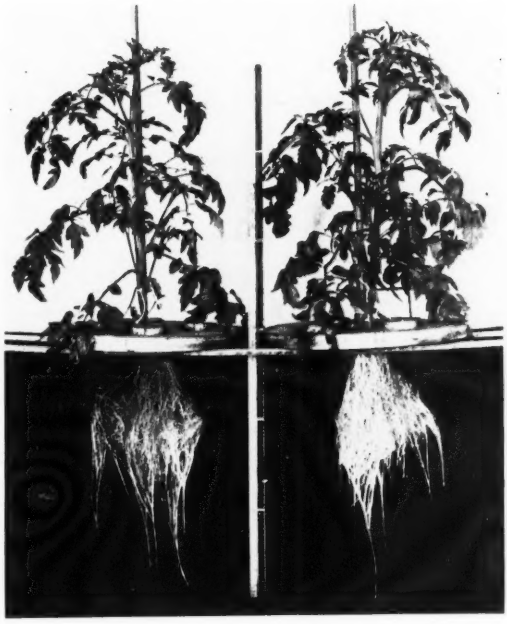

FIG. 2

UNIV OF MICH

THE MEASUREMENT OF "SUCTION FORCES" IN SOILS

CHAS. F. SHAW

California Agricultural Experiment Station

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In an endeavor to measure the force exerted by soils in absorbing or imbibing water, Joffe and McLean (2, 3) used a porous burned clay cup (Pasteur clay filter or filter balloon) filled with water and connected to a mercury manometer. The soil was packed around the porous cup, and as the water was absorbed by the soil, the mercury was lifted until its weight balanced the "suction" force that was developed. The method has been suggested as a means of indirectly measuring the colloidal content of the soils. Hardy (1) has criticized the method on the grounds that it does not take into account the variation in water conductivity of the soils.

In experiments similar to those of Joffe and McLean, we have been unable to get results that show any significant differences between soils of markedly different soil texture. The final results, as measured by the height of the column of mercury, are approximately the same for all the soils tested.

The porous "cups" used were Pasteur-Chamberlain filter thimbles, porous irrigation tubes, and thistle top atmometers. In some experiments the tubes or cups were packed in soil and attached to the usual type of U-shaped mercury manometer; in others, they were placed in percolation cylinders, the connecting glass tubing extending vertically downward into the mercury reservoir; while in some experiments the thistle top atmometers were fitted with collars and the soil was packed upon their upper surface, with a straight tube to the mercury reservoir (fig. 1). Table 1 shows the results from a typical experiment by the latter method. The soils used were Tujunga sand with a total clay content of 2.57 per cent, of which 0.83 per cent was colloidal clay (less than 2 μ effective diameter); Hanford fine sandy loam with 8.35 per cent total clay and 4.59 per cent colloidal clay; and Vina clay loam with 24.73 per cent total clay and 16.35 per cent colloidal clay. In this particular experiment, the atmometers had been soaked and boiled in distilled water to drive out included air and were covered with a uniform depth of 2 inches of soil packed on the absorption surface. Table 1 and curve 4 on the graph (fig. 2) show that the rate and height of rise of the mercury was relatively uniform for each soil, notwithstanding their great differences in texture.

Parallel tests were carried out, a similar atmometer cup, without any soil, being used. The results are shown in table 2 and as curves 1, 2, and 3 on the graph (fig. 2). In this case the rate of rise was much faster and the total

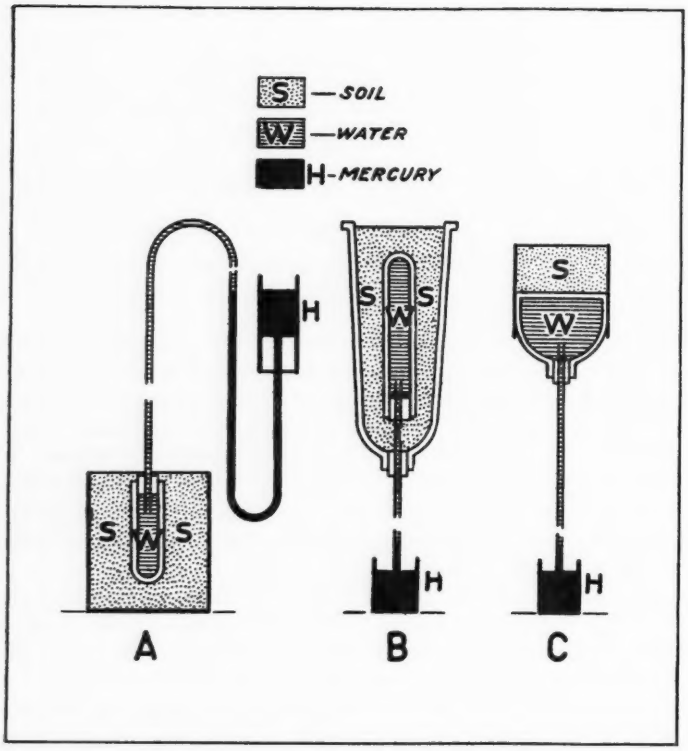

FIG. 1. METHODS OF SETTING UP THE EXPERIMENTS

A—tube packed in soil with usual type mercury manometer. *B*—tube packed in soil in a percolator, with straight vertical glass tube extending into mercury reservoir. *C*—tube (atmometer) with soil packed on its surface, and with straight glass tube to mercury reservoir.

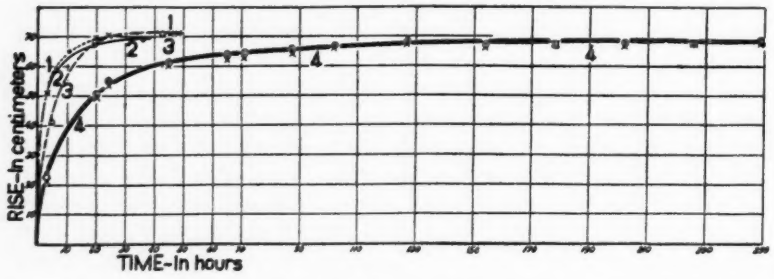

FIG. 2. RATE AND HEIGHT OF RISE OF MERCURY LIFTED BY ATMOMETER CUPS FILLE WITH WATER

Curves 1, 2, 3 are successive tests with surface of cup exposed to evaporation. Curve 4 is drawn through points on three tests using Tujunga sand, Hanford sandy loam, and Vina clay loam.

TABLE 1

Height to which mercury was lifted by porous atmometer cups filled with water and covered with two inches of soil

TIME ELAPSED	HEIGHT OF MERCURY		
	Tujunga sand	Hanford sandy loam	Vina clay loam
hours	*cm.*	*cm.*	*cm.*
0.50	9.00	10.00	11.00
0.83	13.75	12.25	13.75
2.25	22.25	20.00	21.75
2.50	24.00	21.30	23.30
18.90	50.60	49.20	50.80
20.95	53.40	51.50	53.00
22.00	54.30	52.50	53.90
23.50	55.30	53.70	55.00
46.50	60.10	61.30	61.90
47.50	60.30	61.40	62.20
48.75	60.70	61.90	62.60
65.00	62.30	64.00	64.00
67.00	62.60	64.20	64.30
70.00	62.80	64.30	64.50
71.00	62.90	64.50	64.60
87.50	64.60	66.10	66.10
93.00	64.60	66.10	65.90
95.00	64.60	66.10	65.90
102.00	66.00	67.20	67.10
103.50	66.00	67.50	67.15
110.50	66.00	67.60	67.15
127.00	66.60	68.10	67.80
154.00	66.50	67.80	67.50
165.50	67.00	68.40	68.00
178.50	67.00	68.30	67.80
181.00	67.00	68.30	67.80
202.50	67.25	68.60	68.10
222.00	67.80	69.20	68.60
226.75	67.60	69.10	68.40
231.00	67.70	69.20	68.50
246.00	68.00	69.30	68.60
249.00	67.75	69.20	68.60
269.75	67.90	69.40	68.80
293.50	67.70	Dropped	Dropped
298.75	67.60	.....	.....
302.00	67.50	.....	.....
334.00	67.30	.....	.....
342.00	67.20	.....	.....
356.00	Dropped	.....	.....

height somewhat greater than that obtained when the atmometer cups were packed with soil! The lifting force, or "suction" evidently rests in the porous burned clay disc that forms the surface of the atmometer, and not in the soil.

This agrees with the statements of Livingston (4) and others that the "suction" force developed by a clay cup may exceed one atmosphere.

It is our belief that the experiment does not measure the "suction" force of the soil, but that it may to a degree measure the ability of the soil to transport moisture away from the absorption surface. In the experiment shown in table 1 the moisture evaporated from the soil nearly as fast as the atmometer cup could deliver it, and continued until the weight of the mercury caused air

TABLE 2

Height to which mercury was lifted by porous atmometer cups filled with water and exposed to evaporation in laboratory

Columns 1, 2, and 3 show results from three successive tests, the atmometer cups being boiled in distilled water between tests.

TIME ELAPSED	HEIGHT OF MERCURY		
	1	2	3
hours	*mm.*	*mm.*	*mm.*
0.50	21.5	....	....
0.83	21.5	....	....
2.25	48.5	....	....
2.50	51.5	....	....
4.00	....	....	42.1
11.00	....	66.0	....
12.25	....	66.0	....
18.90	69.7	....	....
19.00	....	....	68.9
19.50	....	67.1	....
20.95	70.2	....	....
22.00	70.3	....	69.0
23.50	70.3	....	....
36.00	....	69.1	....
39.00	....	Dropped	....
43.00	....	....	71.0
46.50	71.3	....	....
47.50	71.3	....	....
48.75	71.4	....	....
65.00	Dropped	....	....
66.75	....	....	Dropped

to be sucked into the interior cavity of the atmometer. The air moved in slowly (as shown by the lowering of the mercury columns of the sand tube) at first, but as the air bubble enlarged, the mercury receded at an accelerating rate until it finally dropped.

CONCLUSIONS

The "suction" force of soils, and indirectly the colloid content, can not be measured by the use of porous burned clay or porcelain cups, bulbs, or tubes,

because these porous materials themselves have a high water lifting or "suction" force. The soil may serve to remove the moisture from the surface of the material and thus make possible a continuation of the process until the weight of the mercury lifted overcomes the tensile strength of the water column or the forces which hold the water in the pores of the "cup" material. The soil, however, would not carry any of the weight, nor supply any of the "suction" force. It would function essentially the same as though it were lifting water from a free water surface and would develop a water content essentially the same as that of the capillary rise.

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SOME EFFECTS OF CRUDE PETROLEUM ON NITRATE PRODUCTION, SEED GERMINATION, AND GROWTH[1]

H F. MURPHY[2]

Oklahoma Agricultural and Mechanical College

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The effect of crude petroleum on soils is of practical importance only in the oil field districts and along pipe lines where breaks may occur and allow the crude petroleum to overflow the nearby land. The question of damages under such conditions is continually occurring. Also, after the oil industry in a particular section has given out, the question of bringing the land back to the production of field crops makes the effect of crude petroleum on land an important problem in such cases.

Literature on the effect crude petroleum may have on the soil and further crop production is meager. Several investigators have shown that certain soil organisms have the power to utilize hydrocarbons as sources of energy yet few of these workers have used crude petroleum as the source of hydrocarbons under consideration.

Rahn (4) in 1906 reported a mold found in soils that was capable of breaking down paraffin and utilizing it as a source of food. Söhngen (5) in 1913 reported several organisms that could readily utilize hydrocarbons as sources of energy. By using a special medium, he found that 4 to 8 mgm. of petroleum were oxidized in 24 hours at 28°C. for every square centimeter of surface of solution. Gainey (3) reported that paraffin was detrimental to ammonification and nitrification. Tausz and Peter (6) reported in 1919 some isolated soil organisms capable of decomposing hydrocarbons. They isolated the three organisms *Bact. aliphaticum*, *Bact. aliph. liquefaciens*, and paraffinbacterium which were capable of decomposing hydrocarbons. Carr (2) found that the growth of soybeans was apparently improved when a small amount of oil (up to 0.75 per cent) was added to soil and that a rather large amount (4 per cent) could be added before the soybean plants succumbed to the treatment. Baldwin (1), in studying the modification of soil flora induced by applying crude petroleum, found that the soil flora was considerably changed. Ammonia production was slightly lowered and nitrate production was completely inhibited over varying periods of time. Small applications of crude petroleum, however, did not seem to injure the crop producing power of the soil.

[1] Contribution from the Department of Field Crops and Soils.

[2] Associate Professor of Field Crops and Soils.

EXPERIMENTAL WORK

The experimental work carried on by the writer was divided into two parts: part 1 consisted of studying the effect of crude petroleum on nitrification, whereas Part 2 had to do with the effect of petroleum on seed germination and plant growth. The soil used in both parts is what was classified by the U. S. Department of Agriculture, Bureau of Soils, as "Yahola very fine sandy loam." This is a common bottomland soil found along the streams in the Red Prairie division of the Great Plains region. It is considered a very productive soil in the section where it is found.

TABLE 1

Nitrate content of soils incubated with various amounts of crude petroleum applied in different ways

AMOUNT OF CRUDE PETROLEUM APPLIED	TREATMENT	OCTOBER	NOVEMBER	JANUARY	FEBRUARY
per cent		*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
0	None	132	83	45	56
0.0843	Surface	....*	70	46	41
0.0843	Mixed	....	55	53	37
0.2107	Surface	....	39	44	32
0.2107	Mixed	....	....	....	17
0.4215	Surface	66	34	29	28
0.4215	Mixed	49	8	15	11
0.6322	Surface	....	25	42	15
0.6322	Mixed	....	....	....	8
1.0959	Surface	63	4	28	9
1.0959	Mixed	10	0‡	5	6
2.1918	Surface	16	0‡	10	4
2.1918	Mixed	3	0	0	5
6.5754	Surface	Trace†	0	0	....
6.5754	Mixed	Trace	Trace	0	....

* A blank indicates no sample was run for that period.

† None in one of the duplicates.

‡ One of the duplicates showed a very slight trace.

Part 1

In the nitrification study, 100-gm. samples of soil were placed in glass tumblers and a definite amount of crude petroleum that had a specific gravity of 0.8430 was added. The crude petroleum was used in one of two ways; either it was applied to the surface or it was thoroughly mixed with the soil. The samples were kept at optimum moisture conditions and incubated under greenhouse conditions for one month. At the end of the month, the nitrates were determined by the phenoldisulfonic acid method. Very good checks were secured. The results of these nitrification tests are given in table 1. The tests covered a period of four months, new sets being incubated each month.

The results indicate that even a very small application has a tendency to

reduce nitrate formation. There was very little difference between mixing the crude petroleum with the soil and applying it very lightly on the surface, but as the rate of application increased, mixing the crude petroleum with the soil decreased nitrate production more than did surface application. The application of approximately 0.4 per cent of crude petroleum to the surface cut down the nitrates about one-half, whereas approximately 1 per cent of crude petroleum mixed with the soil practically checked nitrate formation. Even smaller amounts of crude petroleum when mixed with the soil had a very depressing effect on nitrate production. The application of crude petroleum amounting to approximately 0.4 per cent when mixed with the soil very materially checked the formation of nitrates.

TABLE 2

Effect of crude petroleum on the germination and growth of wheat

TREATMENT (ACRE BASIS)	NUMBER OF PLANTS PER PLOT				
	September 24	September 27	September 29	October 5	October 17
No treatment	4	8	22	22	22
15,000 gallons applied to surface	None	None	None	None	None
5,000 gallons applied to surface	None	None	2	5	5
2,500 gallons applied to surface	None	None	2	14	25
500 gallons applied to surface	None	1	22	25	25
15,000 gallons applied at 4-inch depth	None	None	None	None	None
5,000 gallons applied at 4-inch depth	None	1	2	19	22
2,500 gallons applied at 4-inch depth	None	1	20	25	25
15,000 gallons mixed with surface 4 inches	None	None	None	None	None
5,000 gallons mixed with surface 4 inches	None	None	None	None	None
2,500 gallons mixed with surface 4 inches	None	None	None	1	1
500 gallons mixed with surface 4 inches	None	2	7	16	16

Part 2

The effect which crude petroleum has on the germination of the wheat seed and on the growth of wheat was studied on 8½ pounds of soil placed in one-gallon tin containers. These soil samples were treated with various amounts of crude petroleum added in different ways. The cans were buried in the ground so that the surface of the soil in the container was even with the surface of the soil on the outside. The bottom of each container was supplied with drainage holes. Moisture for the germination of the seeds and for the development of the seedlings was supplied by the rainfall during the fall season of 1927. The crude petroleum was added in the following ways to various samples as noted in table 2: (*a*) poured on the surface, (*b*) four inches of soil was removed from the container, the petroleum poured over the surface of the remaining soil in the container, and the top soil put back in place, and (*c*) the crude petroleum was mixed with the surface four inches of soil. Twenty-five kernels of Turkey Red wheat were planted about one and one-half inches

deep in each container on September 9. The first rain after the wheat was planted occurred on September 23, when 1.34 inches fell. Table 2 gives the result of the germination and growth experiment.

Crude petroleum, even in small amounts, generally delayed germination. The containers in which the seed did not germinate were examined on October 19, and it was found that all of the wheat kernels had rotted. Mixing the crude petroleum with the surface was noticeably detrimental to seed germination. Five hundred gallons of crude petroleum mixed with the surface 4 inches of soil reduced the stand 36 per cent compared with the check average on October 17. Twenty-five hundred gallons of crude petroleum applied to the surface gave only approximately 23 per cent of a total stand compared with the check average on October 17. A similar amount of crude petroleum applied 4 inches below the surface did not reduce the final stand on October 17. Mixing any of the larger applications of crude petroleum with the surface soil prevented germination of the seed. Five hundred gallons applied to the surface did not prevent germination but did delay it just slightly, as can be noted under the column dated September 27.

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DETERMINATION OF THE FINENESS OF MARL[1]

E. P. DEATRICK AND CLARENCE DORMAN[2]

West Virginia Agricultural Experiment Station

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The accuracy of the standard method of determining the fineness of marl has been questioned alike by some marl producers and control chemists. Data are herewith presented to show that determinations made according to the standard method—that of calculating the percentages of material of certain finenesses from the weights of the thoroughly dried material held on the screens after thorough shaking—is inaccurate.

It is not reasonable to expect that dry screening would yield accurate results, for the large pieces of marl are not solid, but are balls or granules of finer particles which to a great extent have been formed during the commercial drying process. Apparently recognizing this, different laboratories seem to vary the details of the method of screening.

In one laboratory the marl is gently rubbed through the screens with a rubber pestle. In another the marl is constantly agitated with a spoon handle or similar instrument, but no attempt is made to "force the particles through the mesh or break them down in any way."

It is exceedingly difficult to agitate so that only aggregates are broken up and so that particles are not actually forced through the mesh. Inasmuch as marl closely resembles soil, it would seem natural that the use of the principle employed in determining the fineness of soil would yield more accurate results. Here the sample is deflocculated before screening is attempted.

By screening the marl after it is deflocculated, it has been found, as shown in table 1, that the material is really very much finer than the dry screening test would indicate. The amount of material passing a 0.1-mm. screen is in some cases 70 per cent greater after deflocculation. The deflocculation is conveniently accomplished by placing the dry marl (in this case 10 gm.) in a motor drink mixer as modified by Bonyoucos[3] and allowing it to run for 9 minutes (the time required to deflocculate completely most soils) after 500 cc. of water and 5 cc. of 0.1 *N* KOH have been added. After the samples were

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[2] Associate Professor, Agronomy (Soils) and Graduate Student Assistant, W. Va. Agricultural Experiment Station, Morgantown.

[3] Bonyoucos, G. J. 1927 Directions for determining the colloidal material of soils by the hydrameter method. *Science* 66 (1696): 16.

deflocculated, the suspensions were poured through a battery of soil sieves of 1-, 0.5-, 0.25-, and 0.1-mm. mesh. These were used instead of the customary 20-, 40-, 60-, 80-, and 100-inch mesh sieves because those in our laboratory are too large to put on the pan of the analytical balance. It was found later that the deflocculated marl should be poured on a battery of the 1-, 0.05-, and 0.25-mm. sieves first. The collected water with the material finer than 0.25 mm. should then be poured separately on the 0.1-mm. screen with constant agitation with a rubber policeman so as to prevent clogging of the fine meshes. In this way the determination can be carried out easily and accurately.

TABLE 1

Mechanical analysis of marl

NAME OF MARL	SIZE OF MATERIALS IN MILLIMETERS, DETERMINED BY									
	Dry screening					Wet screening				
	1	0.5	0.25	0.1	>0.1	1	0.5	0.25	0.1	>0.1
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Lime marl	10.0	17.5	13.7	46.7	12.1	0.3	0.7	2.9	12.3	83.8
Precipitated lime	0.0	7.6	18.2	63.3	11.0	0.0	4.2	12.5	25.8	57.5
Alba marl	32.5	22.3	16.9	21.5	6.8	0.5	1.0	4.6	9.9	84.0

TABLE 2

Mechanical analysis of ground limestone

NAME OF LIMESTONE	SIZE OF MATERIALS IN MILLIMETERS DETERMINED BY									
	Dry screening					Wet screening				
	1	0.5	0.25	0.1	>0.1	1	0.5	0.25	0.1	>0.1
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Standard limestone	0.6	8.5	20.0	42.6	28.3	0.0	5.5	15.6	24.0	54.9

For those specially interested in this work, it may be stated that screening of 20-, 40-, 60-, 80-, and 100-inch mesh can easily be secured and inserted in sieve holders such as were used here (no. 12110 from Central Scientific Company).

It will be noticed that, as shown in table 2, dry screening of ground limestone does not completely separate out the material of finest size, though, as expected, the difference between the two methods of screening is not so great as in the case of marl.

EFFECT OF CROP GROWTH ON THE REPLACEABLE BASES IN SOME CALIFORNIAN SOILS

J. C. MARTIN

University of California[1]

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In 1915 there was inaugurated at this laboratory an investigation of a group of thirteen Californian soils from representative agricultural areas in the state. A comprehensive description of these soils as to classification, previous history as far as known, mechanical analyses, hygroscopic coefficients, and specific heats is given by Stewart (10) in a paper presenting the results of the studies of this group of soils during the first two years of the investigations. A more recent paper by Burd and Martin (1) describes the cultural conditions under which these soils have been maintained up to 1924 and reports certain observations on the liquid phases of the various soils, the pH of which range from 6.9 to 8.2.

Since the last mentioned observations were made, three additional crops of barley have been produced by the continuously cropped soils. The soils, which were uncropped from 1916 to 1925 inclusive, were cropped to barley in 1926, and are now under barley crops annually. The present study was undertaken to observe, if possible, changes which may have taken place in the replaceable bases of these soils. They have been maintained under very carefully controlled conditions in that nothing but distilled water has been added, nor has any leaching taken place during the entire period the soils have been under observation.

Concerning the effects of different treatments on the replaceable bases in soils, Page and Williams (6) at Rothamsted have observed those due to long continued annual fertilization of field plots. Smith (8) has noted in some Scottish soils the fairly permanent content of exchangeable bases for a given soil under normal conditions and also the variation from soil to soil. Steenkamp (9) has reported changes in the replaceable bases under the process of dehydration of soils. Of more direct bearing on the observations to be reported in this paper are those recently presented by Fraps (2). Using the ammonium chloride method in 88 tests of soils in pot experiments, he reports that the replaceable potash lost from the soil in supporting two crops is related to that contained in the crops with a correlation coefficient of 0.796.

Briefly, the treatments of these Californian soils since assembling at Berke-

[1] Laboratory of Plant Nutrition.

ley in 1915, are as follows: two duplicate galvanized iron containers (coated with black asphalt paint) were filled with each soil (1800 pounds); the first year all soils were cropped to Beldi barley; one container of each soil has been cultivated and cropped to barley annually up to the present time and in this paper is called the "cropped soil;" the other container of each soil was uncropped but cultivated annually and kept moist from 1916 to 1920, and from then till 1926 given no cultivation nor water; in 1926 the previously uncropped soils were again moistened and cropped to barley after which these observations were made. The soils which were uncropped for ten years but had supported a barley crop in 1915 and again in 1926 are called the "fallowed soils" in this paper. It is clearly recognized that the effect of fallowing alone is not measured in these observations. The term is used only for the sake of brevity in distinguishing them from the continuously cropped soils.

It is not the purpose of this paper to attempt to discuss the mechanism of base exchange, since there are numerous instances in the literature bearing on this phenomenon. It will be limited to a brief discussion of a set of observations made on this group of soils which have been under investigation for 13 years by our laboratory.

METHOD OF SAMPLING AND PREPARATION FOR REPLACEMENT

A portion of each soil was air-dried and screened through a 1-mm. screen in 1915 at the time the soils were assembled for experimentation. These portions have been stored in large stoppered bottles and in these observations are used as representative of the subsequently cropped and fallowed soils at the beginning of the experiment. The sampling of the cropped and fallowed soils was accomplished by taking ten uniformly spaced cores of soil from each soil, extending the entire depth of the container (18 inches). Each sample core was 1 inch in diameter. The ten cores of each soil were then composited, air-dried, and pulverized to pass the 1 mm. screen. The samples thus prepared were then used for the determination of replaceable bases.

METHOD OF REPLACEMENT

The replacing reagent used was ammonium acetate adjusted to a pH of 7.0 and approximately normal, as suggested recently by Schollenberger (7). Twenty-five-gram portions of soil were each treated with about 150 cc. of the reagent in Erlenmeyer flasks, and allowed to digest at about 70°C. for an hour or two then transferred to a Buchner filter and the soil leached with reagent until the leachings showed no test for calcium. This usually required between 400 and 500 cc. of the reagent. The leachings were then made up to a volume of 500 cc. and determinations of the four major bases made in the usual way after removal of excess ammonium acetate, which is accomplished on the steam bath and finally on an air bath with moderate heating.

The results have not been corrected for water-soluble bases which these soils contain, as they are not significant in the magnitudes of the bases re-

ported. In a few cases, determinations have been made of the ammonium absorbed. In the heavy soils this value is about 80 per cent of the total determined bases extracted but in the light soils the agreement on the whole is not so close; in the case of soil 8 it is 55 per cent whereas in soil 12 it is 80 per cent of the bases extracted. Each value reported for the individual bases is the result of a single determination. The data are presented in table 1.

CLASSIFICATION AND TREATMENT OF SOILS

The first and second columns of the table describe the soil classification and give the laboratory numbers of the soils. It will be observed that there are five silty clay loam soils and one clay loam of the same series. The first three of these soils come from the Sacramento valley near Davis and the second three from the Santa Clara valley. It will also be observed that each fine sandy loam soil of this group is from a different series. Soil 7 came from near Arlington; soil 8 from the San Joaquin valley near Fresno; soil 9 from near Redlands; soil 10 from the San Fernando valley; soil 11 from Kearney Park in the San Joaquin valley; soil 12 from near Oakdale in the San Joaquin valley foothills; and soil 14, a virgin desert soil from eastern Lassen county. All of these soils are low in their $CaCO_3$ content, soils 2 and 9 being free from this compound while soils 4 and 5 contain the most, 0.20 and 0.18 per cent, respectively.

The third column shows the cultural treatment of the soils, and here it should be noted that the so-called fallow soils were cropped to barley in 1915 and again in 1926 at the end of which season these observations were made. During the intervening period of ten years these soils produced no crops.

REPLACEABLE BASES IN THE ORIGINAL SOILS

First, if we may confine our attention to the original soils, it will be observed that the amounts of replaceable bases are quite variable, ranging from 38.5 in soil 6 to as low as 6.8 milligram-equivalents in soil 8. As a group the heavy soils contain about twice the amounts present in the light soils. The clay and silty clay loam soils will be called "heavy" while the fine sandy loam soils will be called "light" for the sake of brevity. The spread of values in the former group (24.3 to 38.5 milligram-equivalents) although as great in actual amount as that of the latter group (6.8 to 20.0 milligram-equivalents) is relatively of smaller magnitude, as might be expected from the more variable nature and origin of the sandy loam soils. It will also be observed that there is more variability in the relative proportions of the four bases in the replaceable fractions of the light soils than is the case in the heavy soils. In the silty clay and clay loam group, the calcium and magnesium together comprise 94 to 96 per cent while the potassium and sodium are 4 to 6 per cent of the total. In the sandy loam group the calcium and magnesium together range from 83.7 to 92.2 per cent, potassium and sodium making up the remainder, 7.8 to 16.3 per cent of the total. It may be of interest to note that in soil 1 the magnesium

TABLE 1

Replaceable bases in original, cropped, and fallowed soils*

DESCRIPTION OF SOILS			PER CENT OF WATER-FREE SOIL				MILLIGRAM-EQUIVALENTS PER 100 GM. OF WATER-FREE SOIL		RELATIVE PROPORTION OF BASES (PER CENT OF TOTAL)			
			Ca	Mg	Na	K	Total bases	NH_4 absorbed	Ca	Mg	Na	K
Yolo silty clay loam	1	Original	0.286	0.192	0.007	0.038	31.4	24.9	45.6	50.3	1.0	3.1
		Cropped	0.287	0.195	0.007	0.025	31.2	24.4	45.8	51.2	1.0	2.0
		Fallowed	0.282	0.194	0.012	0.033	31.5	24.6	44.7	51.0	1.6	2.7
	2	Original	0.322	0.101	0.008	0.053	26.0	20.1	61.6	31.9	1.3	5.2
		Cropped	0.322	0.090	0.007	0.041	24.9	20.1	64.6	30.0	1.2	4.2
		Fallowed	0.317	0.087	0.008	0.048	24.5	19.3	64.5	29.1	1.4	5.0
	3	Original	0.412	0.097	0.008	0.059	30.4		67.8	26.1	1.1	5.0
		Cropped	0.412	0.087	0.008	0.045	29.1		70.3	24.6	1.2	3.9
		Fallowed	0.415	0.090	0.007	0.050	29.7		69.7	25.0	1.0	4.3
	4	Original	0.345	0.074	0.006	0.031	24.3		70.8	25.0	1.0	3.2
		Cropped	0.345	0.074	0.004	0.022	24.0		71.7	25.3	0.7	2.3
		Fallowed	0.338	0.072	0.006	0.028	23.8		71.0	24.9	1.1	3.0
	5	Original	0.373	0.068	0.016	0.034	25.7		72.3	21.6	2.7	3.4
		Cropped	0.383	0.061	0.009	0.022	25.1		76.1	20.1	1.6	2.2
		Fallowed	0.376	0.067	0.011	0.031	25.6		73.4	21.6	1.9	3.1
Yolo clay loam	6	Original	0.453	0.171	0.023	0.032	38.5		58.7	36.5	2.7	2.1
		Cropped	0.453	0.157	0.026	0.021	37.2		60.7	34.7	3.1	1.5
		Fallowed	0.464	0.173	0.036	0.025	39.6		58.6	35.8	4.0	1.6
Mean of clay and silty clay loams		Original	0.365	0.117	0.011	0.041	29.4		62.0	32.8	1.6	3.6
		Cropped	0.367	0.111	0.010	0.029	28.7		64.0	31.9	1.4	2.7
		Fallowed	0.365	0.114	0.012	0.036	29.1		62.7	32.2	1.8	3.3
Hanford fine sandy loam	7	Original	0.191	0.031	0.011	0.022	13.1	9.0	72.7	19.3	3.7	4.3
		Cropped	0.194	0.032	0.013	0.016	13.3	8.8	72.8	19.8	4.3	3.1
		Fallowed	0.195	0.028	0.012	0.021	13.1	8.7	74.3	17.8	3.9	4.0
Fresno fine sandy loam	8	Original	0.090	0.017	0.009	0.021	6.8	3.5	66.0	20.4	5.6	8.0
		Cropped	0.093	0.018	0.008	0.007	6.6	3.7	70.3	22.2	5.0	2.5
		Fallowed	0.097	0.017	0.009	0.012	6.9	3.6	69.7	20.1	5.6	4.6
Kimball fine sandy loam	9	Original	0.118	0.021	0.007	0.014	8.2		71.6	20.6	3.5	4.3
		Cropped	0.129	0.020	0.007	0.010	8.6		74.5	19.2	3.3	3.0
		Fallowed	0.132	0.019	0.006	0.013	8.7		75.9	17.5	2.9	3.7
Tejunga fine sandy loam	10	Original	0.246	0.035	0.011	0.047	16.8		73.2	17.0	2.7	7.1
		Cropped	0.229	0.034	0.009	0.034	15.5		73.6	18.3	2.5	5.6
		Fallowed	0.238	0.034	0.010	0.042	16.2		73.5	17.3	2.7	6.5

* Soils cropped in 1915, fallowed from 1916–1925 inclusive, and cropped in 1926.

TABLE 1—*Continued*

DESCRIPTION OF SOILS			PER CENT OF WATER-FREE SOIL				MILLIGRAM-EQUIVALENTS PER 100 GM. OF WATER-FREE SOIL		RELATIVE PROPORTION OF BASES (PER CENT OF TOTAL)			
			Ca	Mg	Na	K	Total bases	NH_4 absorbed	Ca	Mg	Na	K
Madera fine sandy loam	11	Original	0.182	0.049	0.010	0.045	14.7	10.7	61.8	27.4	3.0	7.8
		Cropped	0.187	0.046	0.008	0.029	14.3	10.4	65.6	26.7	2.5	5.2
Arnold fine sandy loam	12	Original	0.115	0.020	0.006	0.016	8.0	6.4	71.3	20.7	3.0	5.0
		Cropped	0.117	0.023	0.005	0.010	8.2	6.4	71.6	22.7	2.5	3.2
		Fallowed	0.112	0.023	0.004	0.015	8.0		69.9	23.4	2.0	4.7
Standish fine sandy loam	14	Original	0.255	0.049	0.011	0.108	20.0		63.5	20.2	2.5	13.8
		Cropped	0.258	0.048	0.013	0.091	19.6		65.2	20.0	2.8	12.0
		Fallowed	0.254	0.048	0.014	0.100	19.8		64.0	20.0	3.1	12.9
Mean of fine sandy loams		Original	0.171	0.032	0.009	0.039	12.5		68.6	20.8	3.4	7.2
		Cropped	0.172	0.032	0.009	0.028	12.3		70.5	21.3	3.3	4.9
		Fallowed	0.171	0.028	0.009	0.034	12.1		71.2	19.4	3.4	6.1

exceeds the calcium by about 5 per cent, the only case where this relationship exists. In the other heavy soils the calcium is from 1.6 to 3.3 times the magnesium equivalence. In soil 14 where we find the greatest amount of replaceable potassium, the ratio of this base to sodium is 5.5 to 1. Generally speaking, however, the amount of potassium is twice that of sodium. In comparing the mean value for the group of heavy soils with that of the group of light soils, it will be observed that calcium makes up a slightly greater proportion of the replaceable bases in the latter than it does in the former. The proportion of magnesium is considerably greater in the group of heavy soils. The proportions of potassium and of sodium in the group of light soils are both approximately twice the values for these bases in the heavy soils group, although the absolute quantities of each of these two constituents in the two groups are about equal.

It is of interest to note that an average of the relative proportions of the replaceable bases in these 13 soils gives values for calcium and magnesium which are quite close to those reported by Kelley and Brown (5) for an average of seven Californian soils of neutral or slightly alkaline reaction. In the latter, however, the sodium predominates over the potassium by a ratio of 2 to 1 while in the soils reported here the potassium exceeds the sodium by approximately the same ratio.

CHANGES IN THE REPLACEABLE BASES

In considering the data from the cropped and fallowed soils with respect to the condition of these soils at the beginning of the experiment, those changes

which are general and significant in magnitude over the entire group should receive major attention.

A comparison of the mean values for the cropped and fallowed soils of the heavy and of the light groups with those for the respective original soils, shows that in each group there has been only a slight and insignificant lowering of the values for total bases. The results for total bases for the individual soils, then, show that there are four cases each in which the cropped and the fallowed soils exceed slightly the original soils.

The mean values for each group of soils seem to indicate that calcium has remained constant, which is a reflection of the behavior of each heavy soil and of most of the light soils. In soils 8 and 9, both cropped and fallowed, there appear to be increases, but these are offset in calculating the mean values for the group by decreases in the case of soil 10.

As judged by the mean values for the group of heavy soils, magnesium shows a slight decrease in the cropped soils, the result of this behavior in four soils (2, 3, 5, and 6). In the cases of the fallowed heavy soils and both cropped and fallowed light soils, the magnesium seems to have remained practically constant.

Sodium seems to undergo no uniform or significant change, the mean values rather show it to be very constant, the result of about an equal number of increases and decreases in both groups of soils.

When we consider the mean values for potassium in each group there seem to be, especially in the cropped soils, very significant decreases. In most of the soils which had been fallowed, the decreases are not so large and in several cases cannot be considered significant. A comparison of the cropped and the fallowed condition of each soil with the corresponding original, shows that in every case there has been a loss. These decreases of replaceable potassium for the most part are very small in magnitude compared to the total replaceable bases but make up a very considerable part of the replaceable potassium present in the original soils. The potassium in the group of heavy soils comprises from 2 to 5 per cent of the total replaceable bases, with a mean value of 3.7 per cent, whereas in the light group it is from 4 to 14 per cent of the total, the mean being 7.2 per cent. It is evident, therefore, that significant changes in this constituent, which makes up such a small part of the replaceable fraction, might not alter the total of the replaceable bases by an amount which would be considered significant.

LOSSES OF REPLACEABLE POTASSIUM

Table 2 shows the losses of potassium, calculated first on the basis of the original content of this constituent, and second as percentage of the soil.

The values are very variable over the whole group of soils but it will be noted that the continuously cropped soils of the sandy loam type show a much wider spread of values both in absolute and relative losses. The behavior of the replaceable potassium in soil 7 is in striking contrast to that in soil 8. These

TABLE 2

Comparison of the losses of replaceable potassium from cropped and fallowed soils with that contained in the crops*

DESCRIPTION OF SOIL			LOSS FROM SOIL		CONTENT OF CROP (PER CENT OF WATER-FREE SOIL)
			Per cent of original	Per cent of water-free soil	
Yolo silty clay loam	1	Cropped	34.21	0.013	0.014
		Fallowed	13.16	0.005	0.007
	2	Cropped	22.64	0.012	0.014
		Fallowed	9.43	0.005	0.007
	3	Cropped	23.73	0.014	0.012
		Fallowed	15.25	0.009	0.006
	4	Cropped	29.03	0.009	0.014
		Fallowed	9.68	0.003	0.007
	5	Cropped	35.30	0.012	0.022
		Fallowed	8.82	0.003	0.009
Yolo clay loam	6	Cropped	34.37	0.011	0.013
		Fallowed	21.87	0.007	0.009
Mean of silty clay and clay loams		Cropped	29.88	0.012	0.015
		Fallowed	13.04	0.005	0.008
Hanford fine sandy loam	7	Cropped	27.27	0.006	0.012
		Fallowed	4.55	0.001	0.005
Fresno fine sandy loam	8	Cropped	66.67	0.014	0.016
		Fallowed	42.86	0.009	0.007
Kimball fine sandy loam	9	Cropped	28.57	0.004	0.008
		Fallowed	7.14	0.001	0.005
Tejunga fine sandy loam	10	Cropped	27.66	0.013	0.016
		Fallowed	10.64	0.005	0.008
Madera fine sandy loam	11	Cropped	35.56	0.016	0.016
		Fallowed	.....	.....	.....
Arnold fine sandy loam	12	Cropped	37.50	0.006	0.009
		Fallowed	6.25	0.001	0.005
Standish fine sandy loam	14	Cropped	15.74	0.017	0.012
		Fallowed	7.41	0.008	0.006
Mean of fine sandy loams		Cropped	34.14	0.011	0.013
		Fallowed	13.14	0.004	0.006

* Soils cropped in 1915, fallowed from 1916–1925, inclusive, and cropped in 1926.

two soils, starting with practically an identical quantity of this base, lost during the 12 years of cropping about 30 per cent and approximately 70 per cent, respectively, of the original supply. Soil 14 has an unusually high replaceable potassium content and this soil continuously cropped shows the greatest absolute loss, but it is also the smallest relative loss exhibited by any of the continuously cropped soils. It is interesting to note that in the cropped heavy soils, with the exception of number 4, an almost uniform amount of potassium was lost from each, and the relative losses are all within a comparatively narrow range, which might have been anticipated from the fact that each of these soils has been classified as belonging to the same series. It may be worth noting, however, that the mean value (0.012 per cent) for the loss of potassium from the group of cropped heavy soils is almost identical with the corresponding value (0.011 per cent) for the sandy loam group, although the relative loss from the former group is about 5 per cent lower than from the latter group. This may be a coincidence.

A literal interpretation of the figures indicates a loss of potassium from each of the fallowed soils. At least three of the soils (numbers 7, 9, and 12) cannot be said to have lost significant amounts. These are the same three soils which show the least absolute losses in the continuously cropped condition. Fallowed soils 4 and 5 show losses which may be considered barely significant, although in the continuously cropped condition their losses are certainly significant. The mean values for losses of potassium from the two groups (heavy and light) of fallowed soils are almost identical, 0.005 and 0.004 per cent, respectively. In the soils which were fallowed, we observe in the group of light soils a greater spread of losses (0.001 to 0.009 per cent) than in the group of heavy soils (0.003 to 0.009 per cent). The losses from fallowed soils 7 and 8 again show up in marked contrast, the former being about 5 per cent and the latter, 43 per cent, of their practically identical original contents.

These wide variations in magnitude of the losses of potassium seem to indicate that there are differences in the nature of the complexes involved in replacement. The differences appear to be accentuated in soils of variable origin, such as the sandy loam group.

COMPARISON OF LOSSES OF POTASSIUM WITH CROP WITHDRAWALS

The last two columns of table 2 show the loss of replaceable potassium from the soils under the two treatments and the amounts of potassium found in the crops removed from these soils, both expressed as percentage of the soil.

First, if we observe the mean values for each group, there are slightly greater amounts of potassium contained in the crops in each case than correspond to the observed decreases of this base in the soils. For the group of heavy soils in the continuously cropped condition, the loss of replaceable potassium accounts for 80 per cent of the potassium withdrawn by the crops from these soils whereas in the group of light soils the corresponding relation is 85 per cent. These are values which agree very closely with that reported by Fraps

(2) in his recent paper. When we compare the results for the individual continuously cropped soils, we find cases such as soils 1, 2, 3, and 6 of the heavy group, and soils 8, 10, and 11 of the light group where there are very close agreements between these values. On the other hand, we observe in the cases of soils 4 and 5 of the heavy group that the decreases correspond to approximately 60 per cent of the potassium found in the crops. In these last mentioned soils there appear to be no striking differences, either in their content of replaceable potassium or in its relation to the total, when compared to those heavy soils in which the losses agree closely with crop withdrawals. In the sandy loam soils 7, 9, and 12, where the decreases of replaceable potassium represent 50 to 70 per cent of the total amount of potassium removed by crops from these soils, we observe that this base constitutes an appreciably smaller proportion of the total replaceable bases than in those sandy loam soils where the decreases are closely related to crop withdrawals. The contents of replaceable potassium in the original soils 9 and 12 are considerably lower than any of the other soils either heavy or light, whereas that of the original soil 7 is the same as soil 8 before cropping; however, in the latter soil (no. 8) potassium constitutes a much greater proportion of the total replaceable bases.

The behavior of soil 14 is noteworthy in that the loss of potassium is significantly greater (0.005 per cent) than the crop withdrawal. It is the only continuously cropped soil in the entire group where this relation clearly exists. A characteristic of this soil distinguishing it from all the others is its unusually high content of replaceable potassium (0.108 per cent), which is approximately double the quantity contained in soil 3, the next in order of magnitude, and seven times the content of soil 9, which contains the least. Although it has been postulated by Page and Williams (6) that there may be a conversion of replaceable potassium to a non-replaceable form, the data here presented indicative of such a possibility are entirely too meagre to be convincing. Hissink (4) has stated that transfer between adsorbed and strong acid-soluble bases cannot occur to any great extent.

The bulk of the evidence at hand seems to indicate that the barley crops have either obtained part of their potassium from the non-replaceable form, or if it has all been absorbed from the replaceable complex, directly or indirectly, there has been a partial replenishment of the potassium in this complex from the non-replaceable form.

It will be observed that the losses of potassium from the so-called fallowed soils are more than accounted for by the two crops of barley removed from each of these soils. In the heavy group the loss is 63 per cent of the crop withdrawal, whereas in the light group it is 67 per cent, in both cases being somewhat lower than the corresponding relation in the respective continuously cropped groups. The striking observation again seems to be that the losses from the heavy soils 4 and 5 are one-half and one-third, respectively, of the crop withdrawals, whereas for the light soils 7, 9, and 12 the relation is one-fifth. To account for the behavior of the three last mentioned soils, one might venture the hypothe-

TABLE 3

*Twentieth-normal HCl extractable bases in original, cropped, and fallowed*soils*

DESCRIPTION OF SOILS			PER CENT OF WATER-FREE SOIL				LOSS OF K (PER CENT OF WATER-FREE SOIL)
			Ca	Mg	Na	K	
Yolo silty clay loam	1	Original	0.349	0.324	0.018	0.042	
		Cropped	0.365	0.325	0.018	0.026	0.016
		Fallowed	0.364	0.321	0.019	0.029	0.013
	2	Original	0.424	0.204	0.030	0.051	
		Cropped	0.431	0.218	0.017	0.056	0.005 (gain)
		Fallowed	0.428	0.215	0.025	0.055	0.004 (gain)
	3	Original	0.273	0.199	0.026	0.061	
		Cropped	0.275	0.203	0.025	0.045	0.016
		Fallowed	0.270	0.204	0.051	0.052	0.009
	4	Original	0.247	0.157	0.026	0.040	
		Cropped	0.253	0.167	0.037	0.026	0.014
		Fallowed	0.253	0.157	0.025	0.031	0.009
	5	Original	0.626	0.139	0.014	0.047	
		Cropped	0.642	0.144	0.013	0.028	0.019
		Fallowed	0.634	0.147	0.022	0.042	0.005
Yolo clay loam	6	Original	0.564	0.368	0.059	0.035	
		Cropped	0.584	0.374	0.049	0.024	0.011
		Fallowed	0.573	0.381	0.053	0.024	0.011
Mean of clay and silty clay loams		Original	0.414	0.232	0.029	0.046	
		Cropped	0.425	0.239	0.027	0.034	0.012
		Fallowed	0.420	0.238	0.033	0.039	0.007
Hanford fine sandy loam	7	Original	0.387	0.063	0.034	0.040	
		Cropped	0.357	0.061	0.025	0.030	0.010
		Fallowed	0.364	0.057	0.021	0.036	0.004
Fresno fine sandy loam	8	Original	0.210	0.035	0.008	0.029	
		Cropped	0.206	0.035	0.008	0.012	0.017
		Fallowed	0.222	0.031	0.012	0.021	0.008
Kimball fine sandy loam	9	Original	0.274	0.027	†	0.020	
		Cropped	0.301	0.027		0.020	0.000
		Fallowed	0.272	0.026		0.021	0.001 (gain)
Tejunga fine sandy loam	10	Original	0.567	0.044	†	0.047	
		Cropped	0.561	0.038		0.046	0.001
		Fallowed	0.557	0.042		0.044	0.003
Madera fine sand loam	11	Original	0.258	0.072	†	0.055	
		Cropped	0.265	0.073		0.039	0.016

* Soils cropped in 1915, fallowed from 1916–1925 inclusive, and cropped in 1926.

† Not determined.

TABLE 3—*Continued*

DESCRIPTION OF SOILS			PER CENT OF WATER-FREE SOIL				LOSS OF K (PER CENT OF WATER-FREE SOIL)
			Ca	Mg	Na	K	
Arnold fine sandy loam	12	Original	0.259	0.048	†	0.019	
		Cropped	0.269	0.049		0.019	0.000
		Fallowed	0.259	0.049		0.024	0.005 (gain)
Standish fine sandy loam	14	Original	0.357	0.124	†	0.126	
		Cropped	0.332	0.112		0.112	0.014
		Fallowed	0.355	0.115		0.124	0.002
Mean of fine sandy loams		Original	0.330	0.059		0.048	
		Cropped	0.327	0.056		0.040	0.008
		Fallowed	0.338	0.053		0.045	0.003

sis that the replaceable potassium had increased during the fallow period of 10 years. If this occurred, the losses of replaceable potassium would agree more closely with crop withdrawals. Unfortunately, the present observations were not made until the fallowed soils had been cropped for one season subsequent to the fallow period. It was observed, however, by Burd and Martin (1) that after eight years fallowing, the displaced solutions from soils 9 and 12 showed the greatest relative increases over their original concentrations; soil 7 remained practically constant, and soil 8 decreased to about half its original concentration. Soil 8, in the so-called fallow treatment, lost the greatest amount of replaceable potassium of any sandy loam soil, over 40 per cent of the amount originally present.

TWENTIETH-NORMAL HCl EXTRACTABLE BASES COMPARED TO THOSE REPLACEABLE BY AMMONIUM ACETATE

It has been suggested by Gedroiz (3) that a 0.05 *N* HCl extraction of a soil until the leachings are practically free from calcium gives a fairly accurate measure of the replaceable bases.

These soils were subjected to this extraction and the results of the analyses of the extracts are presented in table 3. (Compare with values in tables 1 and 2.)

The mean values for calcium in the group of heavy soils show that appreciably more of this constituent has been extracted by the acid. Two soils (no. 3 and no. 4) gave up more calcium to the ammonium acetate, while from one soil (no. 5) much more has been extracted by the acid. In the group of light soils the mean values show twice as much calcium extracted by the hydrochloric acid. Each soil in the latter group with the exception of number 14, shows approximately the same ratio (2:1) between the acid extractable and ammonium acetate replaceable calcium.

As regards magnesium, the entire group judged by the mean values for the heavy and for the light soils gave up twice as much to the 0.05 *N* HCl.

In each soil of the heavy group this ratio is practically constant. In numbers 9 and 10 of the group of light soils, the ratio is not very wide but is in favor of the acid, whereas from the other soils in this group the acid extracted twice as much magnesium.

The mean values for sodium in the group of heavy soils show that the ammonium acetate brought into solution only from 30 to 40 per cent of that extracted by the acid. In the two soils of the sandy loam type where sodium was determined, one (no. 8) shows a good agreement between the two extracting reagents. From the other (no. 7) the acid extracted approximately twice the amount of sodium.

The amount of potassium extracted by the hydrochloric acid is more closely related to that brought into solution by ammonium acetate than is the case with any of the other bases determined. The mean values for this constituent in the two groups of soils show the agreement of values to be a little better in the heavy soils. The ammonium acetate replaceable potassium ranges from 70 per cent, in the case of the group of cropped light soils, to 93 per cent, in the group of fallowed heavy soils, of that extracted by the 0.05 *N* acid.

The results of the extractions by either of these two reagents lead to the same conclusions with respect to calcium, magnesium, and sodium. The amounts of these three bases extracted by 0.05 *N* acid are appreciably greater than those brought into solution by ammonium acetate, but the cropping has not altered the values significantly.

When we consider the hydrochloric acid extractable potassium as affected by cropping, the results do not show losses over the entire group. There are cases such as soil 2 in which both replacing reagents give the same amount of this base before cropping but the acid extractable potassium seems to increase after crop growth. Again in soils 9 and 12 there are appreciable discrepancies between the amounts extracted by the two replacing reagents, especially after cropping. Soil 10 in the original condition and also in the so-called fallow treatment yields an equal amount of potassium to both reagents, but after continuous cropping shows no decrease of 0.05 *N* acid extractable potassium, as it did when treated with ammonium acetate. It is of interest to note that the losses of potassium from the cropped and fallowed soils number 4 and 5, as measured by the acid extraction, agree much more closely with those quantities withdrawn by the crops from these soils. There are other cases such as soil 3, before as well as after cropping, from which both these reagents extract the same amounts of potassium.

It might be stated that the quantities of silica, iron, and aluminum brought into solution by the 0.05 *N* HCl are of substantial magnitudes, which was not the case with the ammonium acetate extractions. This would indicate that the action of the acid was much more deep seated and was probably also bringing other silicates into solution.

To summarize the results presented in table 3 as compared to those in tables 1 and 2, then, the ammonium acetate treatment seems to be a closer

measure of the replaceable bases. The milligram equivalents of total bases brought into solution by this reagent are in much better agreement with the ammonium absorbed by the soils (where determined) than is the case with the 0.05 *N* acid extractable bases when calculated to this basis. The losses of potassium due to cropping are more consistent and quantitatively in better agreement with crop withdrawals of this base over the entire group of soils, when measured by the ammonium acetate replacement.

SUMMARY AND CONCLUSIONS

A survey of the data reported here leads to several conclusions:

There are greater relative variations in the amount of replaceable bases in soils classified as of different origin than within a group of soils of uniform classification. The quantities of exchangeable bases in these clay or silty clay loam soils are generally much higher than in the sandy loam soils.

When the soils were subjected to a prolonged period of cropping annually to barley or were cropped twice with a long fallow period intervening, there were no appreciable changes in the content of total replaceable bases.

There were significant decreases of replaceable potassium in all soils cropped annually for 12 years. Nine of the 12 soils, which supported two barley crops with a 10-year fallow period intervening, show significant decreases in potassium. The content of total bases is not significantly altered by these decreases in potassium, because calcium and magnesium, which comprise 90 per cent of the total, remain constant.

The loss of potassium from the entire group of soils supporting an annual crop of barley for 12 successive years is 32 per cent of that contained in these soils at the beginning of the experiment and is 82 per cent of the potassium removed in the crops from these soils. The losses of potassium from the same original group of soils, which have supported two crops of barley with an intervening fallow period of 10 years, are of questionable significance in several cases, but for the entire group, make up 13 per cent of the original content and constitute 64 per cent of the crop withdrawal.

The data seem to be especially significant, since this experiment has been conducted under conditions which preclude the loss of any of the four bases from the soil except by crop withdrawals.

These relations between losses of potassium and crop withdrawals of this constituent suggest the importance of the replaceable base complex with respect to available potassium in soils.

The 0.05 *N* HCl extractable bases in these soils are compared to the ammonium acetate replaceable bases and their relations discussed briefly.

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THE INFLUENCE OF ORGANIC MATTER AND LIME ON SOIL MOISTURE AND ON THE PERCENTAGE OF CARBON AND NITROGEN IN FIELD SOILS[1]

J. F. MULLER[2]

Rutgers University

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The field experiment on the availability of nitrogenous fertilizers at the New Jersey Agricultural Experiment Station has now been in progress for 20 years. Inasmuch as the treatments have been continuouly the same, with the exception of certain minor changes, the opportunity was taken of making a study of the moisture contents of the soils of certain of the plots as influenced by the fertilizer, manure, and lime treatments.

The experimental field is laid out into forty $\frac{1}{20}$-acre plots, one-half of which receive lime at the rate of 2 tons of ground limestone per acre every five years and one-half receive no lime. The unlimed plots comprise series A, the limed plots series B. The fertilizer treatments are the same for the corresponding plots in each series. Twelve plots, six in each series, were selected for this experiment, and the treatments which are given these plots are indicated in the following outline:

Plot number	*Fertilizer treatment*
4A, 4B	Minerals only*
5A, 5B	Minerals, 1600 pounds cow manure
7A, 7B	Nothing
18A, 18B	Minerals, 1600 pounds cow manure, 16 pounds $NaNO_3$
19A, 19B	Minerals only
20A, 20B	Minerals, 200 pounds wheat or rye straw, 16 pounds $NaNO_3$

* Minerals: 16 pounds acid phosphate, 8 pounds muriate of potash.

The soil is a Sassafras loam, which in some places contains considerable fine gravel.

The rotation for the first five years was corn, oats, oats, wheat, timothy; but in 1913 it was changed to corn, oats, wheat, timothy, timothy. The crop in 1928 was corn. The crop results have been reported in previous papers (1, 2, 3, 4).

[1] Journal Series paper of the New Jersey Agricultural Experiment Station, Department of Soil Chemistry and Bacteriology.

[2] The author, a graduate student at Rutgers University in the department of soil chemistry and bacteriology, is indebted to Prof. A. W. Blair for placing at his disposal the experimental plots, to Mr. A. L. Prince for the nitrogen and pH determinations, and to Prof. J. H. Clark for the rainfall records.

In this experiment nine sets of samples were taken, the first on May 1, the last on July 26. Eight borings, each to a depth of 6½ inches, were made for each sample. This composite sample was then quickly sifted through a 5-mm. sieve, well mixed and a portion of approximately one hundred grams placed in an aluminum weighing can. These samples were then weighed, dried to constant weight at 100°–105°C., and reweighed. The results are shown in table 1. The rainfall record covering the period of the experiment is shown in table 2.

The results in general are what might be expected in a soil of this type, namely, that the addition of organic matter increases the moisture holding capacity, and the periodic addition of lime, by coagulating the fine particles, decreases it. This is clearly shown in table 3, which gives the averages.

TABLE 1

Moisture contents of soils

PLOT	PER CENT MOISTURE									
	May 1	May 8	May 15	May 25	June 7	June 26	July 12	July 20	July 26	Average
4A	15.30	15.15	14.00	15.72	15.91	15.58	14.91	16.07	13.72	15.15
5A	14.56	14.94	14.26	15.53	15.60	15.38	14.94	14.14	12.74	14.68
7A	11.54	10.03	10.36	11.08	16.04	11.01	10.74	10.63	10.46	11.32
18A	15.49	15.71	14.84	15.78	16.38	16.10	15.13	13.80	12.71	15.10
19A	10.41	12.53	12.36	13.57	14.64	13.49	13.07	13.08	11.20	12.71
20A	14.35	14.18	13.11	14.37	15.77	13.25	13.28	12.12	10.44	13.43
4B	11.89	11.41	11.27	11.30	12.84	10.42	11.43	10.29	9.00	11.09
5B	13.23	13.09	13.58	13.71	15.59	14.01	14.09	13.74	11.50	13.62
7B	12.90	11.86	11.52	12.29	12.97	10.82	13.62	11.95	10.90	12.09
18B	14.97	15.62	15.71	16.04	17.54	15.84	17.13	17.36	12.40	16.29
19B	13.09	11.89	11.93	12.59	13.58	12.04	11.98	13.08	10.53	12.29
20B	14.15	13.00	11.95	12.73	13.56	12.75	12.36	11.49	11.88	12.65

It will be seen that the organic matter increases the moisture holding capacity more than twice as much as the lime decreases it. It is also shown that the effect of the organic matter is twice as great on the limed soils as on the unlimed. The differences between plots 4A and 5A were rather unexpected and are only explainable on the basis that 4A lies somewhat lower than 5A and thus receives some drainage water. In a season of as heavy rainfall as this, this tendency becomes more marked than would be the case in one of normal rainfall.

With the exception of the samples collected on July 20 and 26, the soils of plots 18A and 18B show the highest percentage of moisture in their respective series. The exceptions mentioned occur in connection with samples from plot 4A which show a higher percentage of moisture than the samples from 18A. The difference is no doubt due in part to the lower position of 4A and in

part to the fact that the corn on 18A was at this time making much more rapid growth and therefore was using much more moisture.

These soils were analyzed for total nitrogen and carbon; the results are given in table 4, together with the pH values. It is of particular interest to note the low percentage of carbon and nitrogen in the soil from plot 7A as contrasted with that from plot 5A, for example, which is separated from it by only about thirty-five feet. The percentage of nitrogen in 5A is practically double that in 7A. This change has been brought about in a period of 20 years. It is very evident that the manure has been an exceedingly important factor in maintaining the nitrogen and carbon content of the soil of plots 5A and 5B, and also of 18A and 18B.

TABLE 2

Rainfall record April 27 to July 24

DATE	MAY	JUNE	JULY	DATE	APRIL	MAY	JUNE	JULY
	in.	*in.*	*in.*		*in.*	*in.*	*in.*	*in.*
1	0.04	....	Tr.	16	....	....	....	....
2	....	0.11	0.05	17	....	Tr.	....	....
3	....	....	Tr.	18	....	0.67	Tr.	....
4	Tr.	0.27	0.72	19	....	0.13	0.73	....
5	....	0.76	1.18	20	....	0.05	0.15	0.12
6	....	1.38	1.96	21	....	Tr.	0.13	Tr.
7	....	Tr.	....	22	....	....	0.35	Tr.
8	....	....	....	23	....	....	Tr.	0.17
9	0.29	0.05	Tr.	24	....	....	0.33	0.06
10	0.05	0.94	0.07	25	....	....	....	....
11	Tr.	Tr.	0.02	26	....	0.23	Tr.	....
12	0.06	0.05	0.02	27	0.08	0.32	....	....
13	....	Tr.	2.13	28	1.11	0.02	....	....
14	....	Tr.	0.17	29	0.05	Tr.	0.57	....
15	....	0.98	....	30	Tr.	0.05	0.38	....
				31	....	....	....	....

The higher percentage of nitrogen and carbon in the soil from 7B as compared with 7A is undoubtedly the indirect result of the lime that is used on 7B. This plot has consistently given higher yields than 7A and this means larger crop residues returned to the soil; furthermore, on account of the lime, there has been a tendency for volunteer clover to appear on 7B after grain and hay have been harvested, and this has contributed some nitrogen and carbon.

Each year plots 18A and 18B give the heaviest crops for the respective series, and thus large crop residues remain to be plowed under for the succeeding crop. These residues, together with the manure that is applied, add large quantities of organic matter, which is reflected in the increased moisture content and a higher percentage of nitrogen and carbon in the soil of these plots.

Analyses made in 1909, soon after the laying out of the experimental plots, showed the percentage of total nitrogen and carbon in these soils to be 0.112 and 1.22 respectively (1). Table 4 shows that the content of total nitrogen in the soils of 18A and 18B is now 0.134 per cent. This is an increase of 440

TABLE 3

Average moisture content of soils

TREATMENTS	MOISTURE
	per cent
Average of all receiving organic matter	14.30
Average of all receiving no organic matter	12.44
Increase due to organic matter	1.86
Average of all receiving lime	13.01
Average of all receiving no lime	13.73
Decrease due to lime	0.72
Average—unlimed with organic matter	14.40
Average—unlimed without organic matter	13.06
Average—limed with organic matter	14.19
Average—limed without organic matter	11.82

TABLE 4

Percentage of carbon and nitrogen and pH values

PLOT NUMBER	TOTAL NITOGEN	TOTAL CARBON	pH VALUES
	per cent	*per cent*	
4A	0.100	1.16	5.36
5A	0.135	1.51	5.46
7A	0.068	0.71	4.70
18A	0.134	1.79	5.88
19A	0.084	1.15	5.03
20A	0.098	1.32	5.80
4B	0.078	1.04	7.05
5B	0.132	1.75	6.87
7B	0.077	1.09	7.20
18B	0.134	1.73	7.09
19B	0.081	1.14	7.04
20B	0.092	1.24	7.29

pounds of nitrogen per acre $6\frac{2}{3}$ inches in 20 years, or 22 pounds per acre per year. Over the same period, 7A shows a loss of 880 pounds of nitrogen, or 44 pounds per acre per year. Plots 20A and 20B, which receive the same amount of nitrate of soda annually as 18A and 18B, show losses of 14 and 20 pounds of nitrogen per acre per year respectively, so that it is apparent that the increased

nitrogen content of the soils of 18A and 18B is due mainly to the large quantity of organic matter which they receive.

The six soils receiving annual applications of organic matter, either as straw or manure; namely 5, 18, and 20, A and B, show an increase in total carbon over that originally present in 1909, whereas the six which have had no added organic matter all show a decrease in total carbon.

SUMMARY

1. A series of moisture determinations was made on the soils of certain experimental plots.

2. In all cases but one, those soils receiving an annual application of organic matter show a higher moisture content than those receiving no treatment or only minerals.

3. In all cases but two, those soils receiving lime show a lower moisture content than the corresponding soils receiving no lime.

4. The addition of organic matter increased the moisture content approximately twice as much as the addition of lime decreased it.

5. The soils receiving annual applications of organic matter, as manure or straw, show an increase in total carbon over the amount originally present in 1909. Those receiving manure show an increase in total nitrogen also. All other plots show a decrease in these two elements.

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LIME PENETRATION RESULTING FROM SURFACE APPLICATION TO PASTURE LAND[1]

P. R. NELSON

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Considerable conflicting data have been obtained by different investigators on the penetration of lime into different depths of the soil. Wilson (10) found no downward movement of calcium in pots after 12 months of weathering. Practically no penetration was obtained in a sod-covered lysimeter after one year at the Pennsylvania Agricultural Experiment Station (4). Ruprecht (5) showed that an application of lime was almost completely removed from the soil in a lysimeter after a 10-year drainage water study. In a crop rotation study Stewart and Wyatt (7) found in one field, after 3½ years, that there was no evidence of penetration; but in a second field, limed for 14 years, there was a partial neutralization of the second 6 inches. White and Holben (9), as a result of 40 years continuous application of fertilizer to the soil, state that of the 13 per cent of lime lost from the surface, 65 per cent was retained in the subsoil. Van Alstine (8), studying surface applications of lime to Rothamsted soils, found a slight penetration of calcium. McIntire (3) reports that lime applied in a 4-year rotation for 30 years is more completely disseminated through the first 21 inches on a manured soil than on an unmanured soil.

EXPERIMENTAL

The present paper gives the results of a study of the penetration of lime into a Gloucester sandy loam in permanent pasture plots having received different fertilizer treatment. The field consisted of six series of eleven plots, 2 square rods in area, each of which was divided into an east and west half, with ground limestone applied to the east portion in the fall of 1921 at the rate of 2400 pounds per acre. Eighteen of the plots received no fertilizer and were used as a check on the influence of the fertilizer. Those plots to which the greatest application of fertilizers had been made were studied, it being felt that the possibility of an influence upon the lime penetration would be more apt to be manifested in them. In the fall of 1927, samples were taken by Prof. C. P. Jones and the author at depths of 0 to 3, 3 to 6, 6 to 9, and 9 to 12 inches from the eighteen check plots and from those which received an average total application of 640 pounds of potassium chloride, 3840 pounds of acid phosphate, or 1920 pounds of gypsum per acre during the period of the experiment. The

[1] From the department of chemistry, Massachusetts Agricultural Experiment Station. Printed with the permission of the director of the station.

TABLE 1

Analyses of the pasture soils

DEPTH	KCl				ACID PHOSPHATE				GYPSUM				CHECK			
	Limed		Unlimed		Limed		Unlimed		Limed		Unlimed		Limed		Unlimed	
	CaO	pH	CaO	pH	CaO	pH	CaO	pH	CaO	pH	CaO	pH	CaO	pH	CaO	pH
inches	*per cent*		*per cent*		*per cent*		*per cent*		*per cent*		*per cent*		*per cent*		*per cent*	
0–3	0.580	5.70	0.440	4.82	0.623	5.68	0.447	4.99	0.628	5.96	0.454	5.10	0.667	5.70	0.452	4.83
3–6	0.425	5.02	0.420	4.81	0.405	4.95	0.438	4.82	0.453	5.19	0.426	4.90	0.486	4.99	0.454	4.75
6–9	0.458	4.82	0.474	4.82	0.403	4.94	0.424	4.85	0.451	5.10	0.442	4.95	0.488	4.93	0.439	4.85
9–12	0.460	4.85	0.458	4.86	0.427	5.02	0.425	4.92	0.417	5.04	0.420	4.95	0.506	4.99	0.483	4.94

samples were air-dried, and soil particles larger than one millimeter in diameter were discarded.

Two methods for observing the effect of the lime were used: determination of calcium oxide by Hilgard's method, and hydrogen-ion by means of the quinhydrone electrode (8).

From the results shown in table 1, the amount of calcium on the surface of the limed areas indicates that the greater part of it has remained at the point of application, since it is nearly 0.2 per cent greater than on the unlimed portions and also greater than in the lower zones of the limed areas. At lower depths in all cases, except the limed check plots, where there seems to be a trend toward accumulation, there is little evidence of penetration. Indeed, in the case of the acid phosphate and gypsum plots, where considerable more calcium has been added, more of the residual lime has been leached from the soil.

The pH determinations, on the other hand, give indication of penetration in each type of fertilization, which is not apparent from the calcium determinations. With the exception of the gypsum plots and the surface layer of the acid phosphate plot, the unlimed plots show no change in soil acidity as a result of fertilization. The gypsum has shown a tendency, though slight considering the amount which has been added, to neutralize the acidity to a depth of 9 inches. This is not in agreement with most of the results obtained with gypsum. Erdman (2) reports with an application of 1000–2000 pounds per acre that there is an increase in acidity of .21–.27 pH. Cubbon (1), with several soil types, is in agreement with the majority of the workers that gypsum has no effect on soil acidity. The large increase in pH of the surface soil on the limed portions of the plots corresponds favorably to the increase in calcium found in these same plots, but in addition, there are significant differences at lower depths which were not manifest by the calcium determinations. The check plots exhibit a slight penetration as shown by a partial neutralization of the soil acidity to the depth of 9 inches. Acid phosphate apparently has no influence upon the pH, for the results agree closely with those of the check plots at the same depths; but potassium chloride seems to have a tendency to retard the penetration, for neutralization has not occurred beyond the second zone. If the neutralizing effect of the gypsum alone is removed, the same manifestation of penetration is obtained in these plots as is obtained with lime alone or with acid phosphate and lime.

SUMMARY

From a study of the lime content and the pH values of the treated and untreated pasture soils it has been found that the greater part of the calcium has remained at the point of application and exerted its influence there. The pH values show a trend toward a gradual penetration as indicated by a slight, though consistent, neutralization of the soil acidity to a depth of 9 inches. The

only fertilizer which has had the slightest neutralizing effect upon the soil is gypsum and its effect has not influenced the change in acidity caused by the application of lime alone.

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AN IMPROVED SOIL-SAMPLING TUBE

F. J. VEIHMEYER

California Agricultural Experiment Station

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Experience extending over a number of years with different types of tools designed to sample the soil for the determination of its moisture content has shown that a soil-sampling tube properly made gives more accurate and consistent results than those obtained with other devices. In fact, under certain conditions it has been found that the soil tube is the only device which can be used. Where gravel is encountered the pieces may be large enough to prevent the use of either the "post-hole" or "worm" augers, but with the sampling tube described herein it is possible to cut through the gravel and obtain a satisfactory sample. The disadvantages of the soil-sampling tube are its high cost and the difficulty sometimes encountered in removing the tube from the hole in dry soils.

The sampling tube which has been found best suited where quantitative measurements of soil moisture are desired is similar to the tubes usually referred to as the "King soil tube." However, certain changes in the sampling tubes heretofore designed have been found to better to a considerable degree the performance of these devices.

The details of the sampling tube, together with the drive head and point (fig. 1), are sufficiently clear for any competent machinist to follow. Tubes over 5½ feet long are not convenient to use unless holes are first punched with shorter tubes. The maximum length of tubes in one piece used by the writer is about 13 feet. This tube can be used for taking samples to a depth of 12 feet, but three other tubes, a 4½-foot, a 7-foot, and a 10-foot tube, are first used. These three tubes take the samples from 0 to 3 feet, 3 to 6 feet, and 6 to 9 feet, respectively. The tubing is made of seamless cold drawn steel containing 3.5 per cent of nickel.

The success of the sampling is largely determined by the shape of the drive point. The point shown in figure 1 was adopted after trials were made with many other points of different shapes. The point is shaped so that a core of soil is cut without pushing the soil ahead of the point and compacting it, or without compacting the core in the tube. This fact is clearly evidenced by the satisfactory results of measurements of the apparent specific gravity, or volume weights, of soils in place obtained with this tube. The soil tube used by Beckett[1] to make volume-weight determinations was the tube described herein.

[1] BECKETT, S. H. 1928 The use of highly viscous fluids in the determination of volume-weight of soils. *Soil Sci.* 25: 481–483.

Beckett's results show that this tube may be used with confidence for this purpose.

If the point is properly tempered many samples can be taken even in gravelly soil before the point is worn out. However, when either points or heads need replacement or repair they may be removed readily by unscrewing them from the tubes. This also is a unique feature since all other tubes, as far as the writer is aware, have the heads and points permanently attached to the tubes. The taper in the point from $\frac{7}{8}$ inch at the outer end to $\frac{31}{32}$ inch at the inner end has been found to be an essential feature. Points designed by others have straight holes about up to the open end and the opening is sharply constricted. This arrangement is supposed to prevent the core

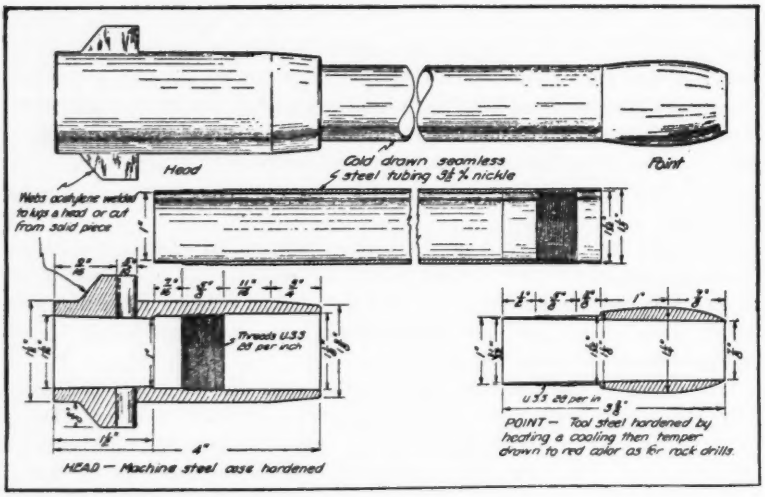

FIG. 1. DETAILS OF SOIL-SAMPLING TUBE

of soil from being pulled out of the tube when the tube is withdrawn from the hole. The use of a straight bore in the drive point is objectionable since it tends to compact the core and offers resistance to the entrance of the core into the tube. The loss of the core can be prevented with the point of the present design by lightly compacting the soil in the tube with a pointed rod before pulling the tube out of the hole. Samples were taken with this tube in fine sand, so dry that other devices could not be used, by pushing the soil lightly with a rod which caused the samples to stay in the tube on withdrawal from the hole. In saturated or nearly saturated clays, samples can not always be kept in the tube but the insertion of a rubber cork in the open end of the head may keep the suction, which results from removing the tube from the hole, from pulling the core out of the tube. The use of the rubber cork in

addition to tamping the core is advisable in all cases where extreme care is desired to retain all of the core in the tube, for instance, as when making volume-weight determinations.

The shape of the head is not so important as that of the point but experience has shown that the head must be tapered on the inside as shown in figure 1. In the present design this taper is from 1 inch at the shoulder to $1\frac{1}{16}$ inches at the outer end of the head. A straight hole in this portion of the head causes the core of soil to lodge and it can be removed only with difficulty. The lugs on the head may either be made as shown in the sketch or the head may be turned down from a large piece of steel, the space between the lugs being planed off. Either arrangement is satisfactory and the cost is about the same

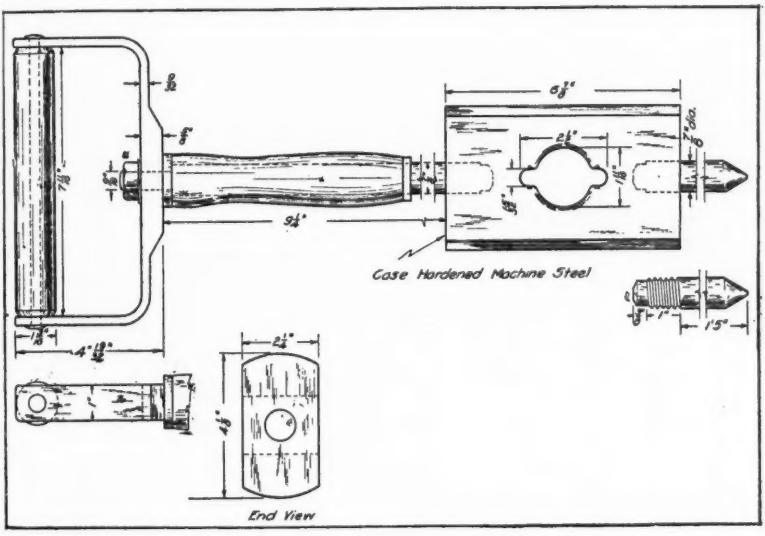

FIG. 2. HAMMER TO DRIVE SOIL TUBE

with either method of construction. When made in large quantities the heads may be cast or drop-forged.

While the hammer may be made in a number of different ways, the one shown in figure 2 has proved very convenient. The hammer shown weighs about 18 pounds. A lighter hammer is not satisfactory except in moist soils. In sampling dry soils a heavier hammer, one which is $7\frac{1}{4}$ inches long, $4\frac{15}{16}$ inches wide, and $2\frac{1}{4}$ inches thick, weighing about 30 pounds, has been found more desirable. The hammer may be made also of cast steel which is subsequently hardened by chilling. When several orders for manufacturing hammers are placed with one machinist the cost may be lessened considerably, since the patterns for the casting can be used a number of times.

The drive hammer can be used to remove the tube from the hole. Usually in moist soils it is sufficient to pass the hammer over the head and give it a quarter turn and pull the tube by means of the lugs. When the tube sticks in dry soils, it may be knocked out of the hole by bringing the hammer up against the lugs with a sharp blow. The core of soil in the tube must be compacted before an attempt is made to withdraw the tube in this way, otherwise it will

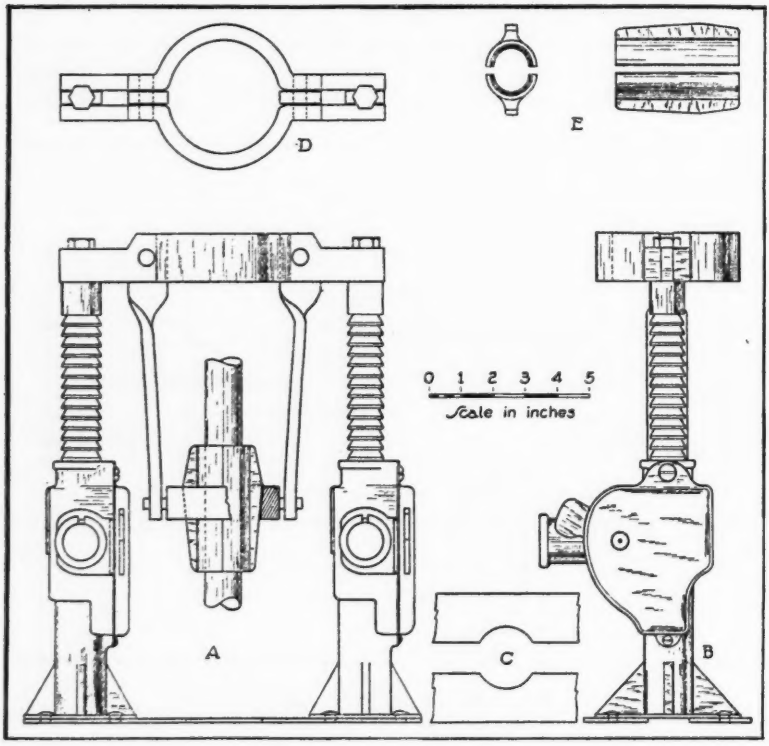

FIG. 3. PULLER FOR SOIL TUBE

be jarred out of the tube The tapered portion of the inner end of the head facilitates withdrawing the tube by jarring it with the hammer. It should be noted that the head and hammer are hardened to prevent them from being battered out of shape. Hardening of the head and hammer is further necessitated by the fact that the core can be removed from the tube satisfactorily only by jarring the head on the hammer. It is never desirable to attempt to push the core out of the tube.

Under some conditions soils are encountered in which the expediency just described of hammering the tube may not be sufficient to pull the tube from the hole and it is necessary, therefore, to use a puller. Figure 3 illustrates a puller which has never failed to work successfully, although its bulk and slowness of operation are disadvantages.

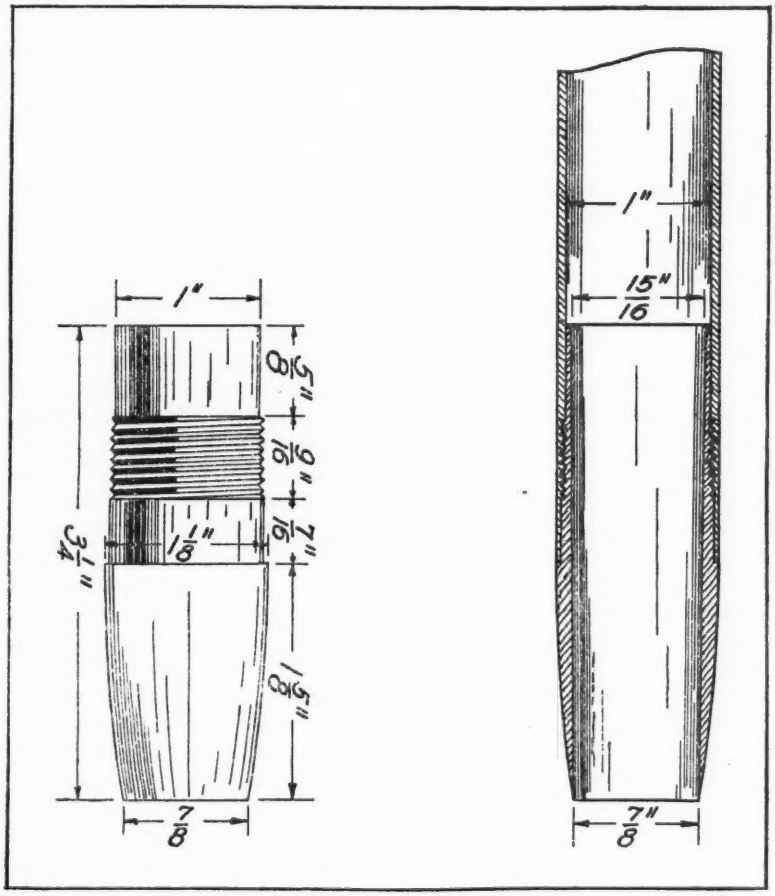

FIG. 4. SOIL TUBE POINT FOR USE IN DRY SAND

The puller consists of two automobile jacks mounted on a base and connected at the top by means of a yoke. The yoke is provided with a circular central opening (fig. 3 D) and the soil tube can be passed through this opening and an opening in the base (fig. 3 C). A ring is suspended from the yoke by

means of two links. The inner surface of the ring is beveled as shown in figure 3 A. Two jaws which are lined with fibre fit into the ring. The diameter of the inner surface of the jaws is the same as the outer diameter of the sampling tube. The rib on each jaw (fig. 3 A, E) is beveled the same as the inner surface of the ring. The operation of pulling the tube from the hole with this device is as follows: The puller is placed over the tube which passes through the opening in the base, ring, and yoke. The jacks are lowered until they occupy their lowest position. They are then raised by working in unison the handles (not shown in the figure). The sliding of the inner surface of the ring on the ribs of the jaws causes the jaws to move together and to grip the tube tightly. An increase of the pull exerted on the tube increases the force with which the jaws grip the tube; the fibre lining of the jaws increases the friction between the jaws and the tube. The inner surfaces of the jaws, having the same diameter as the tube, do not crush the tube even though tremendous forces are developed in pulling the tube. The jacks shown in figure 3 have been found to be most satisfactory since after being raised to their upper limit they will drop back to their lowest position if the trip (fig. 3 B) is released and the handles of the jacks are raised at the same time.

The difficulties, under certain conditions, of removing the tube from the hole have always been a pertinent objection to soil-sampling tubes. The tube with the point described herein offers less resistance to withdrawal from the hole than any of the many kinds which were tested in different soils, and the writer believes its proportions should not be altered except in cases where extreme types of soil are to be sampled. Where deep samples are desired the performance of the tube can be bettered by slightly decreasing the maximum diameter of the point (given as $1\frac{1}{4}$ inches in figure 1) for each tube, the tube with the smallest diameter being used in the deepest hole. In fine sand, a point shown in detail in figure 4 has given good results in taking samples below the upper three feet. The maximum diameter of the point is the same as the outer diameter of the tube so that there is no clearance. Consequently, the sand which is shaken from the sides of the hole when the tube is driven deeper does not lodge behind the point as is the case when points with clearance are used. The point shown in figure 4 can not be used easily in moist loam or clay soils since the soil grips the tube throughout its length and great effort is required to pull the tube from the hole.

Successful operation of the tube depends upon its being kept clean. A small flue cleaner ground down to fit loosely into the tube and screwed onto the end of a rod, when wrapped with steel wool and used in the same manner as a shot gun cleaner, has proved to be very satisfactory for this purpose. The tube is always wiped out with an oil-soaked cloth after being used. When it becomes necessary to remove either the head or the point the tube should never be clamped in a vise nor held with a wrench in such a manner as to dent the tube, because denting prevents the core from being removed easily from the tube. The jaws of the puller (fig. 3 E) can be placed around the tube and clamped in a vise to hold the tube when the head or point is being unscrewed.

EFFECTS OF CARBON DISULFIDE TREATMENT OF SOIL FOR THE JAPANESE BEETLE ON THE ABUNDANCE OF MICRO-ORGANISMS AND ON THE AMMONIA AND NITRATE CONTENT[1]

WALTER E. FLEMING

Bureau of Entomology, U. S. Department of Agriculture[2]

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During the past six years several hundred thousand nursery and greenhouse plants have been grown successfully under commercial conditions in soils which have been treated with carbon disulfide according to the recommendations of the Japanese Beetle Laboratory to destroy the immature stages of the Japanese beetle. Carbon disulfide is used as a gas (1) and also as an emulsion (6) to exterminate the eggs and larvae of the beetle in the soil. Nurserymen have found that many varieties of greenhouse plants usually grow as well in this fumigated soil as in unfumigated soil under normal commercial conditions. The growth of ornamentals which are treated in the field by pouring a dilute emulsion on the soil about their roots is usually inhibited for a short period after treatment, after which they are stimulated into vigorous development.

In view of the great economic value of the ornamental and greenhouse crops that are treated annually, it was decided that further information regarding the effect of these insecticidal treatments on soils should be obtained by studying the results on the numbers of microörganisms and on the accumulation of ammonia and nitrates in the soil.

Many different types of soil are used to grow the various nursery and greenhouse plants. Because of the limited time available for the work, it has been possible to make this preliminary microbiological study on Sassafras loamy sand only. The results obtained, however, are probably indicative of those which would be obtained with other soils. The preliminary results are presented at this time, because there is little possibility of conducting in the near future an extensive investigation of the microbiological effects of the treatments.

It is realized that, under certain conditions, there may be no relationship between the number of microörganisms and the accumulation of their products of metabolism and the growth of higher plants, since other factors than the supply of nitrogeneous matter and the decomposition of plant residues may influence development. In general, it seems reasonable to expect

[1] Contribution No. 47, Japanese Beetle Laboratory, Moorestown, N. J.

[2] The writer is indebted to Dr. J. G. Lipman, director, and to Dr. S. A. Waksman, soil microbiologist, of the New Jersey Agricultural Experiment Station, for suggestions and for the use of equipment during the course of this work.

that plants will not grow properly in a normal, fertile soil if the insecticidal treatment has seriously reduced the number of microörganisms and has caused the accumulation of relatively large quantities of ammonia. If, on the other hand, the treatment has stimulated the development of microörganisms, and has tended to speed up the nitrifying processes, it is possible that the treatment will have been beneficial to the plants.

METHODS OF DETERMINING THE NUMBERS OF MICROÖRGANISMS AND THE QUANTITIES OF AMMONIA AND NITRATE IN THE SOIL

The method used in counting the number of bacteria in the soil is that given by Waksman and Fred (10). A suspension of soil in sterile water is diluted to a convenient and known extent, depending upon the number of bacteria present. One cubic centimeter of the diluted suspension is placed upon a sterile Petri dish and is mixed with melted nutrient agar medium. In these experiments five plates which were prepared for each soil were incubated at 25° to 28°C. for seven days. The number of bacteria per gram of soil was then determined by counting the number of colonies which developed on the plates. The number of fungi in the soil was determined by a similar method, the special acid medium recommended by Waksman (9) being used, and the incubating period being three days. The nitrates were determined colorimetrically with phenol disulfonic acid, and the ammonia was distilled from the soil into a standard sulfuric acid solution in the presence of magnesium oxide, and was determined by titration. Both these methods are described by Fred (4).

EFFECT OF CARBON DISULFIDE VAPOR

A quantity of Sassafras loamy sand was sifted to remove stones and large lumps of soil and to make it homogeneous. It was then divided into 2-kgm. samples, which were placed in jars. One cubic centimeter of carbon disulfide was added to each of five jars, which gave a concentration equivalent to that produced by a dosage of 1 pound per cubic yard. Five untreated jars were used as a control, and all were sealed for a period of 48 hours. The covers were then removed, and sterile cotton plugs were inserted to permit the vapor to escape without subjecting the soil to possible contamination by the bacteria and fungi of the air. No trace of carbon disulfide could be detected in the jars at the end of five days, when the solid covers were replaced. The samples were kept at room temperature, and sterile distilled water was added to each as required to replace that lost by evaporation. Variation in the number and activity of the microörganisms present in the different samples was prevented, to a large extent, by maintaining the samples at optimum moisture content and at a fairly constant temperature.

The number of bacteria and fungi and the quantity of ammonia and nitrate in each sample were determined before the soils were treated with the carbon disulfide. Determinations were also made after 7 days, when the odor of the chemical had disappeared from the soil, and after 33, 66 and 112 days.

The results of these determinations, which are given in table 1, indicate that carbon disulfide applied at the rate of 1 pound to a cubic yard and left in contact with the soil for 48 hours has little effect on the number of bacteria. The treatment stimulated the development of fungi in the soil, the density being approximately three-fold that of the untreated soil throughout the 112 days of

TABLE 1

Effect of carbon disulfide vapor on soil

(Carbon disulfide used at the rate of 1 pound per cubic yard of soil)

DAYS AFTER BEGINNING OF EXPERIMENT	FUMIGATED SOIL				UNTREATED SOIL			
	Number of organisms		Activity of organisms		Number of organisms		Activity of organisms	
	Millions of bacteria per gm.	Thousands of fungi per gm.	Mgm. of ammonia per 100 gm.	Mgm. of nitrate per 100 gm.	Millions of bacteria per gm.	Thousands of fungi per gm.	Mgm. of ammonia per 100 gm.	Mgm. of nitrate per 100 gm.
0	4.1	16.8	0.60	0.146	3.8	19.7	0.60	0.150
7	5.8	71.0	0.69	0.150	5.1	22.6	0.65	0.146
33	5.3	86.1	1.00	0.146	6.2	29.1	0.60	0.146
66	4.5	95.0	1.10	0.155	5.8	31.0	0.70	0.150
112	3.1	104.3	2.00	0.150	3.1	36.0	0.90	0.150

TABLE 2

Effect of carbon disulfide emulsion

DAYS AFTER START OF EXPERIMENT	SOIL TREATED WITH CS_2 EMULSION				SOIL TREATED WITH WATER				UNTREATED SOIL			
	Number of organisms		Activity of organisms		Number of organisms		Activity of organisms		Number of organisms		Activity of organisms	
	Millions of bacteria per gm.	Thousands of fungi per gm.	Mgm. of ammonia per 100 gm.	Mgm. of nitrate per 100 gm.	Millions of bacteria per gm.	Thousands of fungi per gm.	Mgm. of ammonia per 100 gm.	Mgm. of nitrate per 100 gm.	Millions of bacteria per gm.	Thousands of fungi per gm.	Mgm. of ammonia per 100 gm.	Mgm. of nitrate per 100 gm.
0	3.0	27.0	0.20	0.146	2.9	28.0	0.20	0.146	3.0	27.6	0.20	0.146
3	0.2	1.0	0.00	0.146	2.5	3.0	0.00	0.146	2.9	27.8	0.00	0.146
10	21.0	2.4	1.00	0.146	2.9	4.6	0.00	0.146	3.8	28.0	0.20	0.146
17	30.0	3.1	0.90	0.121	5.0	12.9	0.60	0.186	4.0	27.0	0.30	0.146
23	16.3	4.0	0.89	0.126	7.7	29.3	0.60	0.200	5.1	25.2	0.00	0.150
30	17.6	8.4	2.15	0.150	4.0	37.6	0.60	0.186	6.2	29.1	0.00	0.146
59	16.4	32.9	2.00	0.150	3.7	32.0	0.60	0.150	5.0	28.0	0.20	0.150
150	5.6	66.6	2.10	0.150	3.5	28.0	0.80	0.150	3.1	36.0	0.60	0.150

observation. There was no change in the concentration of nitrates but there was an accumulation of ammonia in the treated soil.

EFFECT OF CARBON DISULFIDE EMULSION

Six 4-kgm. samples of sifted Sassafras loamy sand were placed in inverted bell jars, the lower openings of which had been covered with muslin and were

treated by percolating 4 liters of a dilute emulsion containing 2 gm. of carbon disulfide through each mass. An equal number of samples was treated in the same manner, but with water containing no carbon disulfide, and a third group, consisting of untreated samples, was placed in glazed earthen jars to serve as controls. The treatment of loose soil with large quantities of water or of dilute emulsion altered the structure of the soil and caused it to puddle. As the samples were still saturated with water after three days, they were removed from the bell jars and spread on heavy paper to dry. After two weeks, when the moisture content of the treated soils was about 50 per cent saturation, the samples were placed in glazed earthen jars and kept at 50 per cent saturation by the addition of sterile distilled water as required. Samples of each soil were taken at intervals for determination of the number of bacteria and of fungi and the quantity of ammonia and nitrate present.

The results of these determinations, shown in table 2, indicate that the treatment of loose Sassafras loamy sand with a large quantity of water causes a decrease, followed by an increase, in the number of bacteria and fungi in the soil. The increase in the number of organisms was accompanied by an increase in the rate of accumulation of ammonia.

When diulte carbon disulfide emulsion was used in place of water, there was a more marked decrease in the number of bacteria and fungi, followed by a greater increase in the number of these microörganisms. There was also a greater accumulation of ammonia, and a slight decrease in the proportion of nitrates.

RESULTS

The fumigation of Sassafras loamy sand with carbon disulfide at the rate of 1 pound to 1 cubic yard caused a change in the number of bacteria and of fungi per gram of soil and in the concentration of ammonia. On the seventh day after treatment, when all odor of the fumigant had disappeared, the number of bacteria per gram was almost the same as in the original soil, and this did not change greatly throughout the 112 days of observation. In view of the facts established by Waksman and Starkey (11), Hiltner and Stoermer (5), Russell and Hutchinson (7, 8), Fred (2, 3), and others, it is probable that a slight reduction in the concentration of bacteria in the soil would have been observed if a determination had been made while the fumigant was present in the soil. It is also possible that if more than 1 pound of the carbon disulfide had been used, a more pronounced reduction of the number of bacteria, followed by a rapid increase in their density, would have been observed, such as normally occurs when soil is partially sterilized with higher concentrations of this compound. The fungi, on the other hand, were greatly stimulated by fumigation with the small quantity of carbon disulfide that was used. The fungous flora, which was simplified by the treatment, consisted largely of species of *Zygorhynchus* and of *Penicillium*. These fungi were three times as abundant in the treated soil as all fungi in the original soil. The nitrate content of the

soil was not appreciably reduced; the ammonia increased from 0.6 mgm. to 2 mgm. per 100 gm. of soil. In view of these changes, it is probable that the organic matter in the soil had been modified so as to be more available to higher plants. The accumulation of ammonia in the treated soil might prove detrimental to the growth of some greenhouse plants, particularly if the soil were stored where it was not well aerated and if the nitrifying organisms could not develop readily. It appears to be important, therefore, that, in treating soil by this procedure, precautions be taken to aerate the soil thoroughly after fumigation to prevent the accumulation of ammonia in toxic concentrations.

Treatment of loose Sassafras loamy sand with 0.05 per cent carbon disulfide emulsion resulted in puddling of the soil and a great change both in the numbers and in the nature of the microörganisms present. Fungi were almost eliminated, and recovered very slowly. Bacteria were destroyed, but became active and multiplied rapidly as the excess moisture evaporated, so that by the end of the seventeenth day they were ten times as numerous as in the original soil. There were few nitrifying organisms left in the soil, however, because the ammonia content had increased from 0.2 mgm. to over 2 mgm. per 100 gm. It remained at this high concentration for 120 days, while the nitrate content was appreciably reduced. It is apparent that a loose soil, when treated with a large volume of dilute emulsion, such as was used in this test, suffers a detrimental change in its physical structure. The decrease in nitrates and the accumulation of ammonia are probably injurious to higher plants, and may account, in part, for the injury sustained when the soil remains puddled or saturated with dilute emulsion for several days. In well-drained, undisturbed soil in the field the effect of treatment with carbon disulfide emulsion probably resembles that of fumigation, since thousands of nursery trees have been treated successfully on soils of this type.

SUMMARY

A Sassafras loamy sand was treated with the concentrations of gaseous and of emulsified carbon disulfide used for the immature stages of the Japanese beetle, and observations were made on the effects on the microörganisms and on the concentration of ammonia and nitrates in the soil.

Treatment with 0.05 per cent carbon disulfide (1 pound to 1 cubic yard) did not affect the density of the bacterial population appreciably, but it stimulated the development of fungi. It also caused an accumulation of ammonia.

Treatment under laboratory conditions with 0.05 per cent carbon disulfide emulsion was not satisfactory. The detrimental effect on the bacteria and fungi, the accumulation of ammonia, and the decrease in the concentration of nitrates in the soil are probably factors involved in causing the injury following treatment of ornamentals in poorly drained fields, or in fields puddled by the application of large volumes of water. It is probable that the results of treatment of well-drained, fertile soils with this concentration of carbon disul-

fide emulsion are very similar to those of fumigation when the same quantity of the gas is used.

Treatment with 0.05 per cent carbon disulfide, either as gas or as emulsion, results in an accumulation of ammonia and in a change in the numbers of microörganisms. Care should be taken to aerate the soil after fumigation, and the emulsion treatment should be used only in well-drained soil, so as to avoid, as far as possible, excessive accumulations of ammonia.

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AMERICAN SOILS AS SEEN BY RUSSIAN INVESTIGATORS

J. S. JOFFE

New Jersey Agricultural Experiment Station

AND

I. ANTIPOV-KARATAEV

Dokuchaev Soil Museum, Leningrad

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The First International Soil Science Congress held in Washington, D. C., in June, 1927, and the transcontinental tour through the United States and Canada of over two hundred delegates opened a new chapter in the development of soil science. For the first time in the history of this relatively young science a gathering of the most prominent representatives from all over the world has come about. Almost all the branches of soil science have been brought together and an inventory of the accumulated knowledge has been made. These have been correlated and systematized, and a great program for the furtherance of the science has been laid down. The discussions at the meetings and the interchange of views have had a profound effect on the immediate methods of attack of various soil science problems and have opened new avenues of approach to the many complex problems of the science.

One of the outstanding features of the Congress was the "invasion" of the Russian viewpoint on soils. The large, illustrious delegation with the late Dr. K. D. Glinka as the leader made a concerted effort to put across the Dokuchaev school of soil science, a purely Russian creation. An attempt was made by the Russians to fit into their scheme the soils of the North American continent. Their plan is based on comparative morphological soil characters and the climatological and geological data placed at their disposal by the American workers in the field of soil science. Much was drawn from the extensive store of knowledge of American soils possessed by Dr. Marbut, who prepared an elaborate guide for the members of the soil tour.

Several of the Russian investigators who participated in the meetings and in the tour have since published their observations. The purpose of this paper is to summarize their views. Of the five papers that came to the attention of the reviewers, two—one by Kravkov and the other by Tulaikov—are of a general nature and deal but little with the soil phase of the Congress and tour. On the other hand, the papers by Prasolov (1), Vilenskii (3), and Tyurin (2). are concerned with the soil science aspect of their observations and findings.

I. Vilenskii presents a sketchy account of the general geographical characters of the United States and southern Canada. He deals with the orography,

geology, climate, and, somewhat in detail, the flora of the country. With this as a basis, Vilenskii constructs a classification and makes up a map of the soil cover of the country presenting two soil maps: one of the soil regions as submitted by Marbut and one of his own.

Vilenskii fits the soils of the United States and Canada into a system of zonal distribution of soils: 1. The soils of the subtropics (thermophytogenic[1]); 2. The soils of the temperate belt (phytogenic); 3. the soils of the cold belt (phytohydrogenic). Besides these zonal belts one may find intrazonal: 1. Solonetz-like soils (phytohalogenic); 2. Solonchak (hydrohalogenic). In addition to the intrazonal belts Vilenskii gives also the extrazonal-marsh soils (hydrogenic)—and the vertical zones—mountain soils (orogenic).

All of the mentioned types of soil were found by Vilenskii in the United States and Canada. Still he recognizes that "*in America there is not the zonation of soils in our sense of the word, neither latitudinal nor longitudinal, but there is a checkerboard pattern in which each soil square will to a certain degree be similar to the one either to the south or west. This, however, is only true for the soils of the central plain; the soils from the southeastern portion of the United States are distributed in belts running from northwest to southeast.*" This peculiar distribution is explained by Vilenskii[2] as follows: "In North America the direction of the isohyetal line is in general perpendicular to the direction of the isothermal, while in Russia they are more or less parallel."

In describing the various soils of the United States and Canada, Vilenskii uses the comparative method, always comparing the types of soil encountered with the known types of Russian soils. Thus he describes the soils in Minnesota (near St. Paul) and Illinois (near Moline) as podzolized soils on a red, carbonate-free moraine. The whitish podzolized horizon terminates at a depth of 30 to 40 cm. The podozolized soils were also found in the Canadian Rockies at Jasper Park on various parent materials such as limestone and local moraines. Podzolized soils were also encountered in the Appalachian region, from the southern portion of Indiana and Ohio. But there the soils "may belong to the yellow-red division of soil formations, being an intermediary formation between the true yellow-red and the primary podzolized soils of the Great Lake region. . . . . "

"Grey forest soils were found in many places: in Minnesota, Alberta (near Edmonton), Iowa, and the southern portion of Missouri, where these soils are developed on loess. . . . ."

"The chernozem type of soils was found in the prairie soils of Canada and at Fargo, North Dakota. Some degraded chernozem was encountered in Iowa and Missouri. The southern type of chernozem was found in the form of a gray variation in central Kansas at Fort Hays. . . . ."

[1] The nomenclature in parenthesis is original with Prof. Vilenskii. In general, however, the system of zonal distribution of soils dates back to Dokuchaev and Sibirtzev. J. S. Joffe.

[2] The reason for this peculiar distribution expounded by Vilenskii was explained by Dr. Marbut on several occasions while on the Soil Science Congress tour. J. S. Joffe.

"Typical chestnut soils[3] were not met, as we crossed that region by train at night."

Vilenskii points out that the majority of their delegates saw for the first time the subrropical soils. "There is no ground, as Glinka pointed out, to subdivide the yellow and red soils as distinct types of soil formation, as they are stages of the soil formation in one and the same subtropical zone. The yellow soil is an early stage of subtropical weathering and the red soil developing parallel with the yellow is a later stage. The representative types of this soil were found in Virginia, North Carolina, Georgia, and Tennessee. They are found even further north, in New Jersey and Pennsylvania. . . . ."

"Because of the development of the yellow and red soils on several parent materials and because of variation in relief, these soils are very different in their color and other properties."

The reddish brown soils of California are a puzzle to Vilenskii. He says: "One may argue whether the red coloration is due to the soil-forming processes or whether it is a property of the soil-forming parent material." And again: "Thus the red type of soil formation and the red soils of America are distributed under conditions of abundant precipitation in a continental climate of the eastern states, in the desert climate of the high plateau of the Rockies, and on the Pacific coast, irrespective, in the latter case, of the rainfall. It is therefore necessary to depart from the view that these soils are a product of 'the moist tropical and subtropical climate.' "

Finally Vilenskii touches upon the characteristic features of the salinized soils of America. He agrees in a way with Widtsoe (Yearbook of the U. S. Department of Agriculture, 1921) that "the great deposits of alkali and alkali-impregnated soils are associated with the geological history of the country. In early geological days salt lakes, similar to the Great Salt Lake, were no doubt formed which were dried by the changing climate leaving great masses of salt that were later covered by washings from the hills."

Vilenskii, who has studied alkali soils quite extensively, promises to treat the alkali soils of America in a separate paper.

II. Prasolov[4] speaks highly of the work of the Bureau of Soils, especially the division of soil survey and mapping. He finds fault with the maps, which are difficult to read because of the poor selection of colors and the inconsistency of nomenclature of soils in the various sections of the country. "The maps are in part a sort of an agricultural land survey. They represent an arbitrary classification of soils based on the separation of 'types' according to their mechanical composition, and 'series of types' according to the sum of their properties, but in the limits of a given region. At present there are 240 series and 2900 types. In recent years Dr. Marbut and his associates have con-

[3] These follow the southern type of chernozem in the Russian scheme of soil classification. J. S. Joffe.

[4] The section on Prasolov's observations has been written up entirely by Antipov-Karataev and translated by Joffe.

structed a new system of classification based not on the sampling of accidental layers of soil, but on the study of the natural cuts and their genetic horizons."

Prasolov presents the proposed system of Marbut and compares it with the known Russian classification. The new system is as follows:

1. Podzol group in the northwestern states.
2. Jersey group of yellow and brown soils (the "brown earth" of Ramann).
3. Red-brown soils of the south.
4. Dark soils of the prairie in the central states (corresponding chiefly to the leached chernozem of Russia).
5. The Dakota group-steppe soils (corresponding to the Russian southern chernozem).
6. The group of the dry western steppe soils (corresponding to the chestnut soils found in southern Russia).
7. Desert soils (corresponding to the grey soils of Turkestan).

The author carefully presents the facts which justify the classification. First he explains the cause of the meridinal distribution of soil zones in America. It is the meridinal distribution of the mountains in the western part of North America and the absence of high mountains on the Atlantic coast that are responsible for the phenomenon observed. For this reason the eastern states represent temperate-humid and forest regions. As we go westward these regions change gradually first into the prairie region with a more pronounced continental type of a climate and then into the steppe and desert regions. The break takes place at the Rocky Mountains. The end of the desert region is located in the depression between the Rockies and the Sierras. The disturbance in the proper zonation is brought about by the influence of the warm gulf stream from the Gulf of Mexico, which runs alongside the southeastern coast of North America. The continentality of the southern climate is thereby obliterated. On the other hand, the cooling influence of the cold Laborador stream and of the Hudson Bay on the northwestern portion of the country is worth mentioning. These two reasons change the picture of the soil cover in the eastern portion of North America, placing the podzolized soils in the northern forest region, the "brown soils of Ramann," somewhat to the south, and the red soils in the south. The same forces influence the prairie soils.

Prasolov discusses the prairie soils quite extensively. In the neighborhood of Kansas City he found degraded chernozem, and 400 kilometers west of it, the so-called southern chernozem. The same type of soil was found in the southern portion of Canada. From there it extends south to the parallel 310 north latitude in Texas. The author is reluctant to draw too close an analogy between the prairie soils and the Russian chernozem, considering that "the analogy to the prairie chernozem may perhaps be found in the region of the southern mountain steppe."

After enumerating several other local series of chernozem soils[5] as given by

[5] Prasolov describes the chernozem soils in Iowa, which take in about ten series with an acid reaction; the chernozem of Canada, which formed on a carbonate moraine; the chernozem which developed from rendzina; and the extreme members of the chernozems—the humid-meadow-humus soils with a carbonate horizon, near Winnipeg.

the American scheme of classification, and describing their characteristic features, Prasolov stresses the importance of the problem of comparing the Russian and American classification.

"West of the prairie the plain rises, the climate becomes more dry, salinizing processes appear, and the zone of chestnut soils is formed with the well-known flora of our southeast." Prasolov goes on to describe the light chestnut, somewhat salinized soils with the characteristic columnar structure in the horizon at a depth of 20–50 cm. "Further west, in the southern portion of California the grey soils may be noted; one may find there alkali soils with a lower compact marl layer."

Prasolov makes a point in noting the soils in the more humid belt of California where the Mediterranean type of climate prevails. There one may find the surface layers of the soil to be light brown and leached. Whenever these soils "formed either on the eluvium of the parent rock or on the ancient transported deposits, the lower horizons attain a reddish tinge." Similar soils may be found on the southern shore of Crimea.

III. The paper of Tyurin on the soils of North America is based not only on observations of morphological characters of the soils, but also on some chemical analyses made on samples procured by the author. It is therefore a fitting supplement to the papers of Vilenskii and Prasolov.

According to Tyurin the territory of the United States and the southern portion of Canada may be divided into three chief regions distributed in a meridianal direction. The climatic conditions, character of vegetation, and prevailing types of soil formation may serve as a basis for these broad divisions.

"The eastern region represents a forest area, characterized by a humid climate with soils that belong to the podzol type of soil formation. It includes the Coastal Plain, the Appalachians, and the adjacent region toward the west and northwest portion of the Mississippi basin. . . . ."

"Next comes the plains region extending to the Rockies. This has been a grass country until settlements were established. The grass cover is richer in the eastern, more humid region (tall grass), than in the dry western region (short grass). This is the region of chernozem-like, chernozem, and chestnut soils which distribute themselves in a meridianal direction and which alternate as we go westward. . . . ."

"The last region is that of the Rocky Mountains, characterized by a dry climate and by desert or semi-desert vegetation and soils."

Tyurin, like his colleagues, recognizes "that because of the peculiar relations between temperature and rainfall in North America with respect to longitude and latitude, the soil-forming processes are influenced and each region may be subdivided into a series of belts not only in meridinal but also in latitudinal direction."

With the tentative classification of Dr. Marbut (see review of Prasolov's paper) as a basis, Tyurin presents data first on the New Jersey group. The eastern representatives of this group possess the characteristic features of the

podzolized type of soil formation. It differs from the true podzolized soils by its clearly expressed brownish or yellowish-brown coloration of the B horizon. Tyurin considers the western representatives of this group as genuine podozolized soils. These soils developed under mixed forests at an average yearly temperature of 12°C. and 1200 mm. of rainfall.

Tyurin made the following determinations: hygroscopic moisture, humus, loss on ignition, chemically combined water, absorbed bases, and pH.

The Sassafras series (N-E representative of the New Jersey group) take a position intermediate between the true podzolized soils and the red soils. They approach the red soils, inasmuch as they have an accumulation of the sesquioxides in the B horizon, as judged by the high amount of absorbed CaO (0.24 per cent) and MgO (0.02 per cent). The humus content drops from 7.32 per cent in the A_1 horizon to 0.27 per cent in the B horizon.

The western representatives of soils do not differ from the podzolized soils in their humus content (5.84 per cent in A_1 and 0.45 per cent in B), chemically combined water (1.38 per cent in A_1, 1.42 per cent in A_2, and 3.36 per cent in B), and absorbed bases (0.041 per cent CaO and 0.014 per cent MgO in A_2; 0.4 per cent CaO and 0.17 per cent MgO in B). These analyses are on the Miami series in Indiana.

The southern representatives of this group present a peculiar problem. In a way, they are yellow soils as judged from the color of the A horizon, while they may be looked upon as red soils as judged by their B horizon. Tyurin concludes that it may become necessary to discard the term "yellow soil," as it seems to be an intrazonal formation in the zone of the red soils, agreeing to call "red soils" those which have a red B horizon.

The amalgamation of the yellow and red soils into one subgroup is in agreement with the scheme of Dr. Marbut for these soils.

These soils, having the structural features of the podzolized soils, must be classified with them: the A_1 horizon is shallow, 3–5 cm. deep with a slightly dark coloration of humus; A_2 is 15–20 cm. deep with a light-yellowish coloration, which gradually changes into an orange-red in the B horizon. These soils differ from the typical podzolized soils in that they have a low content of absorbed bases (0.006 per cent CaO and 0.003 per cent MgO in A; 0,01 per cent CaO and 0.003 per cent MgO in B), a low capacity for base exchange, and an unsaturated condition. The high content of chemically combined water in the B horizon (6.88 per cent) seems to be an indication of the destruction of the constituents to the point of the hydrates of the sesquioxides and to a decrease in the degree of dispersion.

The region of the plains is divided by Tyurin into three belts: 1. Prairie plain, 2. Chernozem, 3. High plain-chestnust soil.

The author thinks that the prairie belt "reminds one of the forest steppe in the boundaries of the degraded chernozem." Alongside the degraded chernozem type of soils the author found in this belt also some brown soil (Knox soil). Tyurin is inclined to place the Cherokee soils into a type which devel-

oped after having gone through some solonetz stages. The presence of amorphous silica seems to substantiate his findings. Tyurin does not commit himself about these soils, since his considerations are based on one analysis only.

The northern portion of this belt contains more humus (7.88 per cent in the Clarion soils) than does the southern portion (3.05 per cent humus in the Marshal soil). Both soils are slightly acid and in both of them horizon B has an accumulation of the colloidal fraction which came down from the A horizon. The amount of absorbed bases and the chemically combined water in these soils bring them close to the degraded chernozem.

The soils of this belt developed under conditions of grass vegetation with a moisture regime capable of supporting forests, which, however, were not apparent in this belt because of prairie fires, as pointed out by Shantz.

The next belt—the chernozem—occupies a territory of 150–200 km. and traverses the states, beginning in central Texas, through Oklahoma, Kansas, Nebraska, western portion of South Dakota, North Dakota, Manitoba, Saskatchewan, and Alberta. It stretches over a distance of 2000 km. from north to south. The temperature and rainfall in the northern portion being different from those in the southern, make the representative types of the soils also differ. As a representative of the southern group, Tyurin takes the soil at Fort Hays, Kansas, with 3.41 per cent of humus, 0.50 per cent absorbed CaO, and 0.066 per cent MgO in the A liorizon. The northern group as represented by the soils from Brandon, Manitoba, Saskatoon, and Edmonton have a higher humus content in the A horizon, namely 7.39 per cent, 7.38 per cent, and 16.03 per cent respectively.

The third belt extends from the second up to the Rockies with still less precipitation and about the same temperature as in the chernozem belt. Analyses are presented of the soil from Tribue, Kansas. This soil, notwithstanding its lighter color, contains about the same amount of humus—3.15 per cent—as the soil at Fort Hays, which belongs to the chernozem belt. At the Rockies the soils begin to resemble the type of brown soils.

Tyurin considers the soils of the Rocky Mountains as soils of a typical mountain region with characteristic vertical zonation, and speaks but little of these soils. Not much is said about the soils west of the Rockies and no experimental data are presented.

Tyurin sums up his report as follows:

1. Because of the specific physico-geographical conditions of the North American continent the chief soil zones, which may be characterized by definite types of soil formation and which coincide with the chief zones of natural vegetation, are distributed in a longitudinal direction. This zonality of the first order is primarily the result of a corresponding distribution of atmospheric precipitation on the territory of the continent.

2. Within the borders of the zones of the first order, because of temperature differences from north to south, certain subzones in respect to the latitude may be noted; these may be considered as zones of the second order. They are differentiated by various types of soil formation.

3. In addition to the chief natural factors in soil formation—temperature and rainfall,

which determine these zones—there are local and sometimes more than local factors of soil formation which influence the soil in the same direction as temperature and rainfall. At times these factors influence the soil formation in the reverse direction thereby causing certain departures from the zonations indicated. Of these factors the most important are: the age of the soil, drainage conditions, the parent material, and the human factor. Examples of the significance of the first factors were noted on the red soil group, also on the northern portion of the chernozem belt. The presence of a special subzone, caused by the human factor, may be found in the chernozem-like soil of the eastern portion of the prairie.

4. Summing up all the factors of soil formation and their territorial distribution, the North American continent presents many peculiarities as one attempts to compare it with the portion of Eurasia known to us. A more complete study of these peculiarities will offer a chance to develop that viewpoint in soil science which has as a basis the idea of geographicity of soils.

The review of the papers by the three Russian investigators shows a marked similarity—with the exception of minor differences on the intrazonal soils—of opinion, which is based on the system of zonal divisions of soils. This fact seems to indicate that the genetic approach as laid down by Dokuchaev, is the proper method for the study of soils.

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INTERNATIONAL ASSOCIATION OF FORESTRY EXPERIMENTAL STATIONS TO HOLD CONGRESS IN SWEDEN

At the invitation of the Swedish Institute of Experimental Forestry, silvicultural research workers and representatives of the Forestry Experimental Stations will hold a congress in Stockholm at the College of Forestry from July 22 to July 27, 1929.

The preliminary program lists the following subjects for discussions:

Reorganization of the International Association of Forestry Experimental Stations and the adoption of rules whereby it shall be governed.
Arrangement for an international bibliography of forestry.
Discussion on the question of the standardization of measuring methods and the investigation of experimental plots.
Discussion on methods and terminology in the sphere of forestry soil science.
Addresses describing the progress of silvicultural research.

During the congress and for a week preceding and a week following it, excursions will be conducted to different forest regions in Sweden.

The International Association of Forestry Experimental Stations was founded in 1891 for the purpose of discussing at international meetings and conferences questions of importance to the work of forestry research, of facilitating the scientific exchange of ideas between the different institutes, and, wherever possible, of working out standard methods for the carrying out of forestry investigations. The Stockholm congress will be the seventh meeting of the association.

Persons planning to attend the congress are requested to notify Arvid Lindman, Chairman of the Board of Governors, or Henrik Hesselman, Director of the Swedish Institute of Experimental Forestry, and to submit further proposals regarding subjects of discussion, at the same time mentioning any addresses which they may desire to give during the congress.

Enquiries and other communications concerning the congress should be addressed to Statens skogsförsöksanstalt, Experimentalfältet, Sweden.